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Mohler fiber optic network :

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MOHLER FIBER OPTIC NETWORK

Requirements and Performance Specification

Paul E. Spencer

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ABSTRACT

A prototype optical fiber LAN suitable for the needs of the various departments in the Mohler Building is described. Operation is initially at $830nm$ for a CSMA/CD LAN protocol, with future plans to implement a Token Bus protocol at $1300nm$. The Mohler LAN is built as a hybrid star bus composed of insertion connectors, $62.5/125\mu m$ multimode fiber and biconically tapered optical star couplers. This architecture was chosen because of its reliability and ability to support high traffic loads. The LAN design and implementation is described in this article with comprehensive power loss and bandwidth analyses.

1. Introduction

Lehigh University has built a research center for Industrial and Manufacturing Systems Engineering in the Mohler Building. This building houses many research laboratories including the Manufacturing Technology (Man-Tech) lab, the Computer Integrated Manufacturing (CIM) lab and the Robotics lab. The Overall needs of the Industrial and Manufacturing Systems Engineering departments, along with their various research activities, dictate a strong need to provide the Mohler Building with a high-speed integrated Local Area Network (LAN) that is reliable and easy to maintain[1]. The Mohler LAN will fulfill the communication needs of the various departments housed in the building. These needs include a need to integrate existing computer communications equipment with a building-wide network and a desire to provide everybody with access to the campus backbone and other outside networks. These needs are addressed in figure 1.

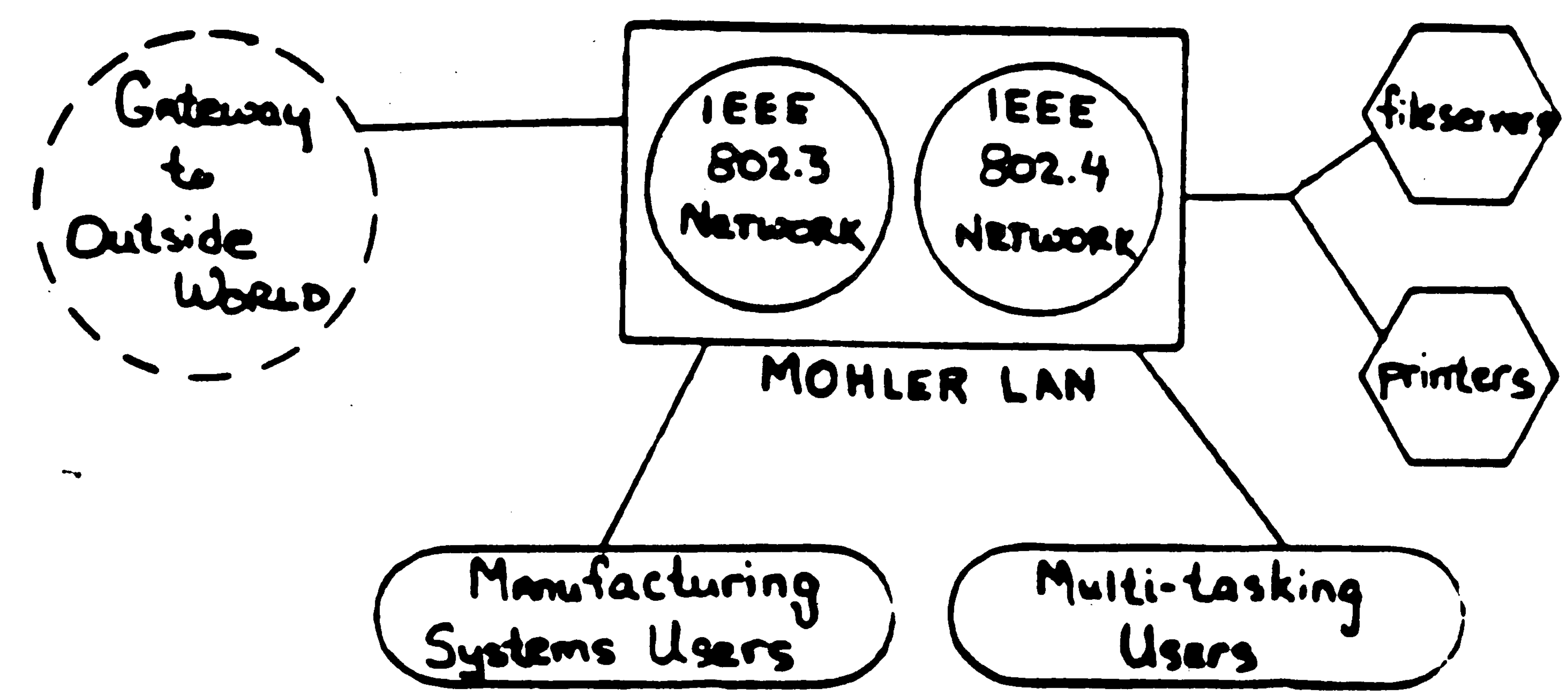

Figure 1. Functional Schematic of Mohler Network

Figure 1 shows a functional schematic of the Mohler LAN. The central portion of the figure shows the Mohler network supporting its LAN protocols. The Network figure has connections to two groups of users — manufacturing systems users and multi-tasking users. These users share the LAN for access to local communication resources such as fileservers and printers. They also have access to the outside world, which includes connections to the campus backbone network and other external networks such as internet and bitnet. The following two subsections explain the Mohler building needs and how they are filled by the LAN design. The first section presents the various objectives of the LAN design, and the second section outlines the procedures used to implement the design.

1.1 Network Objectives

The Mohler LAN is designed to fulfill the communication needs of the various departments in the Mohler building. The building houses many small isolated networks using various types of transmission media. The IEEE 802 family of LAN protocols is best suited for the Mohler network. These protocols can be implemented on many physical media including optical fiber, coaxial and twisted pair cable. This is a very important attribute, because it provides compatibility among networks using different transmission media.

The IEEE 802 LAN protocol family is suited for the Mohler network because it is laid out with a layered hierarchy. Each layer in the protocol hierarchy (suite) is specified in terms of general tolerances rather than exact specifications[2]. Communication functions are broken up into a series of sub-functions. Each sub-function is implemented with a specific protocol layer and passes its outputs to the inputs of the next higher layer in the suite. This concept leads to standardized layers and interfaces between these layers, where the LAN communication functions are described by their inputs and outputs at these interfaces.

The network transmission medium lies at the lowest layer in the protocol hierarchy. The characteristics of this medium provide the framework and limitations on which the remainder of the network is built; therefore, it is necessary to choose a proper backbone transmission medium to optimize a particular LAN design. The Mohler LAN is best served by using graded index multi-mode optical fiber for its transmission medium. Multimode fiber is easy to splice and has an extremely large bandwidth (>300MHz); also, it is not prone to ground loop and electromagnetic interference (EMI) problems that traditionally plague electronic transmission media. The Mohler building is very susceptible to these type of problems. It is an old building which houses various types of heavy industrial machinery.

It is very convenient to take advantage of the available bandwidth of fiber by using Wavelength Division Multiplexing (WDM). It is possible to map many LAN protocols simultaneously on the same optical fiber transmission medium[3]. This attribute allows a LAN to be completely flexible as to which protocols it can offer; additional LAN protocols may be changed or added to the Mohler network by taking advantage of WDM.

1.2 LAN Development

The Mohler LAN design was implemented initially as an IEEE 802.3 network. This may change in the near future with the addition of an 802.4 LAN protocol. The LAN design is divided into three distinct sections. This is reflected in the organization of this thesis. The first section evaluates ring and bus layout topologies for their possible use in the Mohler LAN. The second section characterizes the 802.3 and 802.4 LAN protocols with respect to their operation with an optical fiber transmission medium, and the last section summarizes the issues necessary to maintain, support and expand the Mohler LAN.

2. Physical Layout

Two main issues are important for the Mohler LAN project. The first issue deals with the topology of the physical LAN layout. The layout topology determines the basic structure from which the remainder of the network is built. The second issue deals with communication access to the transmission medium. Once the physical LAN topology is determined, it is necessary to implement communication protocols. These LAN protocols define access methods to the transmission medium, and in turn, provide the network with a communication environment.

The LAN layout is traditionally configured with a bus or ring topology. Both types of topologies have advantages and disadvantages with a particular LAN design. A Ring topology is based on point-to-point communication access. Each station in the ring receives data from its nearest neighbor and later retransmits it on towards its final destination. Data flows from one node station to the next along its entire route, subsequently reaching its final destination. This is depicted in figure 2.

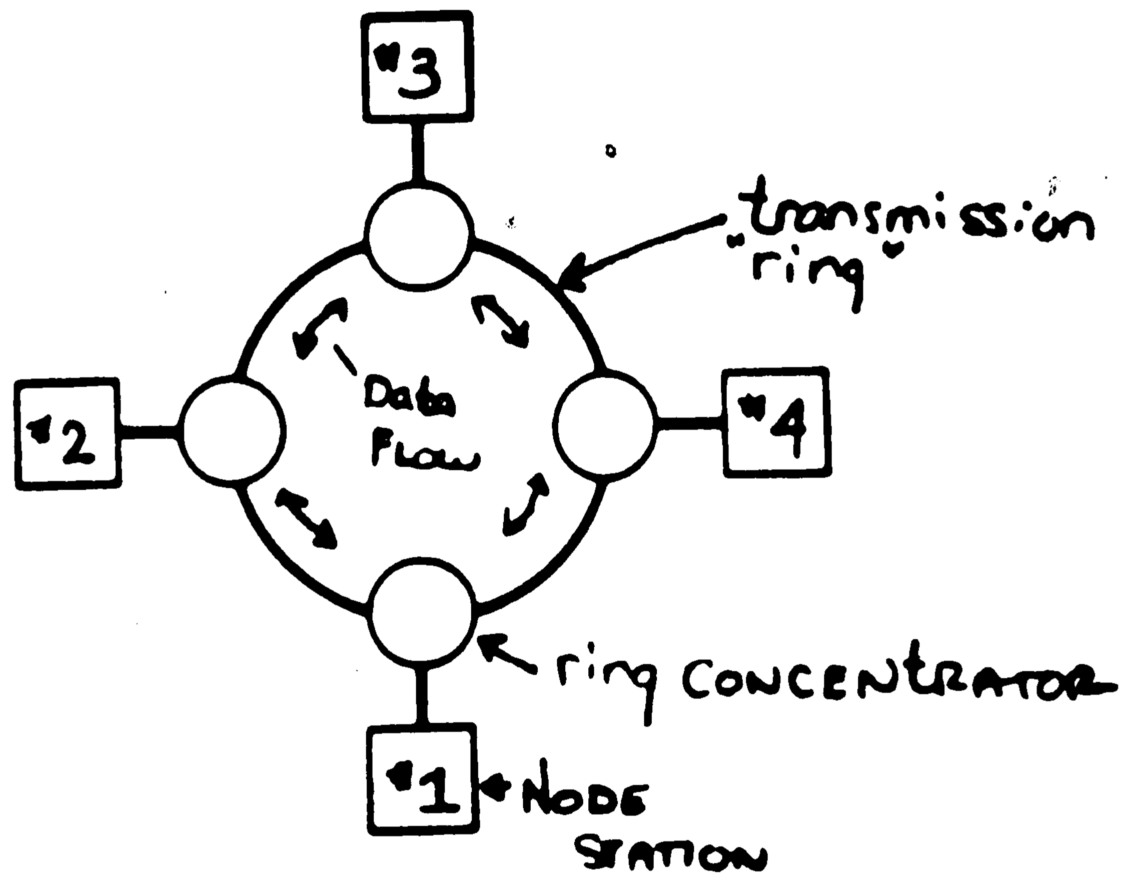

Figure 2. Physical Ring Layout

The figure shows four node stations connected with a ring topology. Data travels out onto the ring through the node station's communication port — a device called a ring concentrator. The ring concentrator serves two functions:

- It serves as a node station data access port to the network transmission medium.
- It receives signals coming into a node station and, after verifying them for errors, retransmits them onto the next ring concentrator in line on the ring.

This is illustrated in figure 2. Node Station 1 wants to talk with node station 3. Data flows from node station 1 to the ring concentrator at station 2. Station 2 verifies the data for correctness and retransmits it onto station 3.

A bus topology is based on multi-point communication access. This term is used to describe multiple node stations connected to the same transmission medium, all of which are capable of communicating. This is illustrated in figure 3 with a schematic of a LAN having a bus topology.

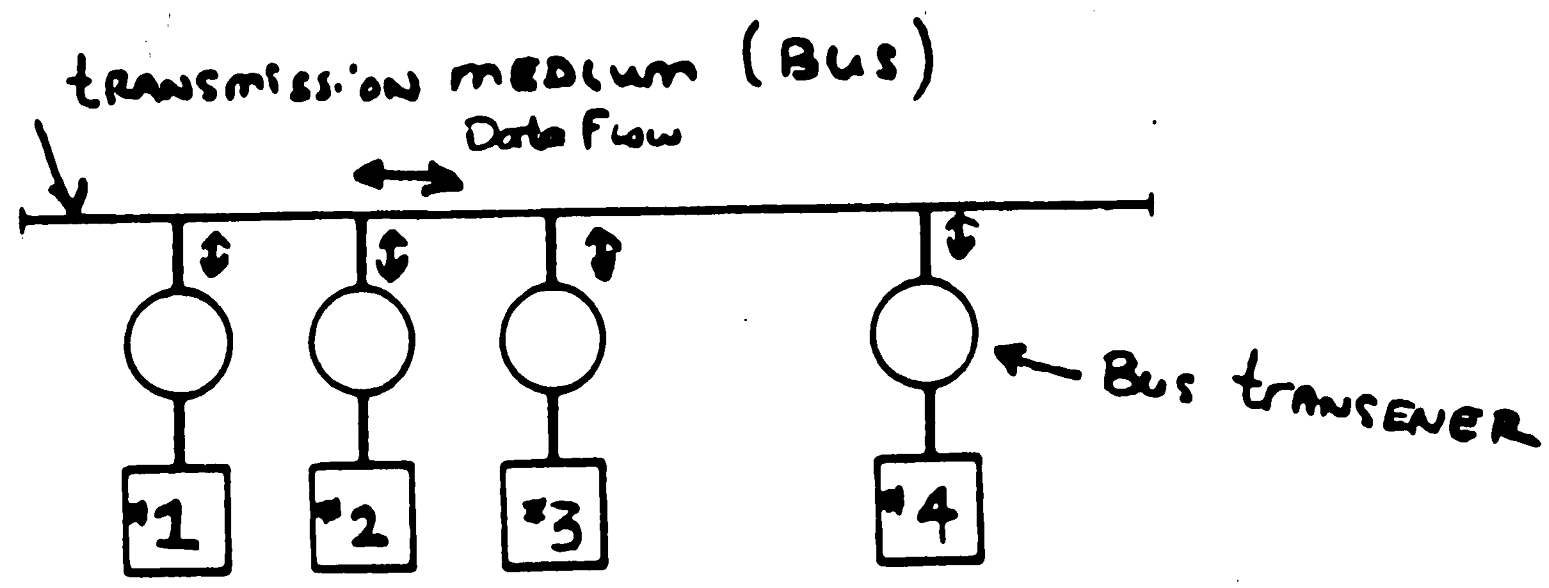

Figure 3. Physical Bus Layout

The multi-point nature of a bus layout gives rise to two methods of data transfer from source to destination. All node stations on the bus share the same transmission medium. Only two stations may, at any one time, actively communicate with each other[2]. If node stations 1 and 2 wanted to communicate at the same time with node station 3, one station would have to wait until the other was through communicating; for instance, node station 2 would have to wait until 1 was through communicating with node station 3.

The second method involves broadcast transmission. Since every station shares the same transmission medium, it is possible for any one station to send data to all other stations on the network. This is extremely useful for broadcast data transmission needs. For example, node station 1 in figure 3 initiates a broadcast transmission. All of the other node stations connected to the bus can receive the data simultaneously, as long as they don't actively participate in the transmission initiated by node station 1.

The Mohler Network is characterized by having a high density of nodes and short length of uninterrupted fibers. These are essential features of Local Area Networks[4]. Figure 4 shows a layout of the Mohler building LAN.

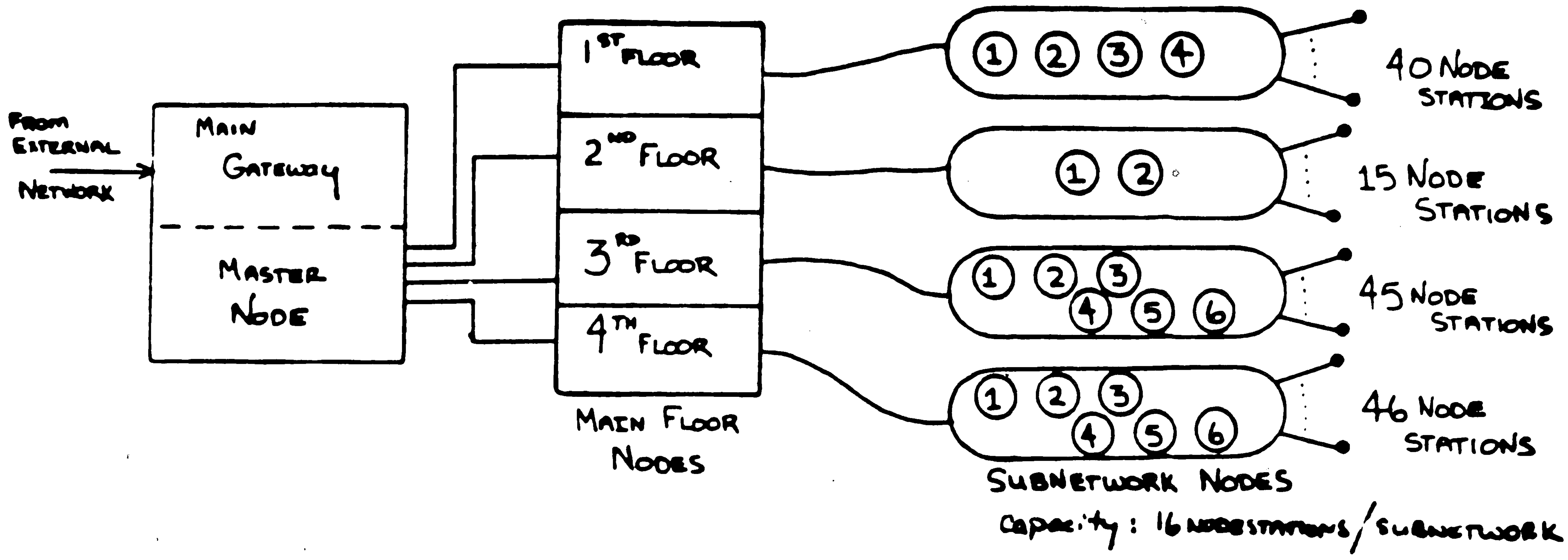

Figure 4. Mohler Building LAN Layout

The Mohler LAN is distributed among four floors in the building with each floor containing a number of sub-networks. Each sub-network provides connection for up to 16 node stations. For instance, the figure shows that the first floor has 4 sub-networks with 40 planned node stations, leaving enough room for a total of 64 stations. There is also plenty of capacity for expansion on the other floors with their sub-networks. The sub-networks on a particular floor are connected to a main communication node called the main floor node. The floor node is responsible for managing data traffic sent to the sub-networks on a particular floor; it is used as a concentration point for all data leaving that floor. The master communication node is responsible for managing data traffic sent to each of the main floor nodes. It serves as a central concentration point for all data traveling between floors in the Mohler building and as a data gateway to the external campus network.

The LAN transmission medium is arranged with a bus topology and is built from transceivers and Passive Fiber Components (PFCs), which consist of multimode optical fiber, mechanical insertion connectors and biconical tapered optical star couplers. This arrangement best serves the networking needs of the building, because the bus layout is a simpler and more cost effective system to implement than its ring counterpart. Passive taps are used rather that active ring concentrators. Active components are usually the most expensive and least reliable parts of a fiber optic LAN design.

The bus layout used for the Mohler LAN is arranged with a hierarchical structure. The term *tree* is used sometimes to describe such a layout. The LAN layout is characterized by the data transmission capability of the bus and is described in terms of the bus bandwidth and loss. The bus bandwidth is a measure of the maximum data modulation rate that can be supported on the optical bus by the transceivers. It would seem at first, that the bus layout would hinder data transmission rates. Bus layouts have one major shortcoming — they suffer a severe loss of data integrity at high data rates[2]. Careful analysis of the situation reveals that this will not be a problem with the Mohler LAN. The Mohler LAN bus has fiber optic cable lengths less than 100 meters long. These short cables have very low loss and have negligible affects on the upper bandwidth of the LAN.

The link loss of the LAN bus describes the maximum serial optical power attenuation from one transceiver to another and has loss contributions from the all the PFCs including the insertion connectors, optical fiber and optical star couplers. Figure 5 shows a portion of the bus in the Mohler LAN. The link loss for node station 1 is determined by the losses associated with an optical signal traveling from a transceiver to a star coupler and back again to the transceiver. These losses include the insertion losses of the transceiver connectors, the optical fiber losses between the transceiver and star coupler and the insertion losses of the star-coupler port connectors. The maximum link loss found in the LAN, along with additional safety margin, determines the needed power budget to operate the LAN. The power budget must be less than that the power available from the LAN transceivers[1]. The Mohler LAN power budget is discussed in more detail in section 3 of this paper.

2.1 Design Issues

Figure 5 shows a functional schematic of the Mohler physical link. The figure depicts a sub-network containing three node stations. The node stations are connected to a single optical star coupler with multimode fiber optic cables. For example, node station 1 wants to send data to node station number 3. The transmitter in station 1 converts the data to optical signals and sends it down the optical fiber cable. The star coupler receives the signals at one of its input ports and distributes the signals back out of its output ports. The signals are then sent back to each of the node stations and up to a higher level node. Optical energy is accepted by the star coupler at its input ports split up and sent out each of the output ports; therefore all node stations receive signals transmitted from all other node stations, including the node station originating the transmission.

It is necessary to look at issues concerning network power requirements, attenuation specifications and network bandwidth limitations to gain an understanding of the Mohler LAN operation. The following sections analyze a typical portion of the physical link that is used to inter-connect three nodes in the Mohler LAN. The analysis includes details of the physical components that are used to implement the physical link; they include transceivers and various

1. Typical LED Transceiver equipment is limited to a 30dB dynamic range in sensitivity. Physical Link designs should limit total link loss so that it does not exceed the available power budget.

PFCs[5] (16 X 16 optical star-couplers, multimode fiber cable and mechanical insertion type connectors).

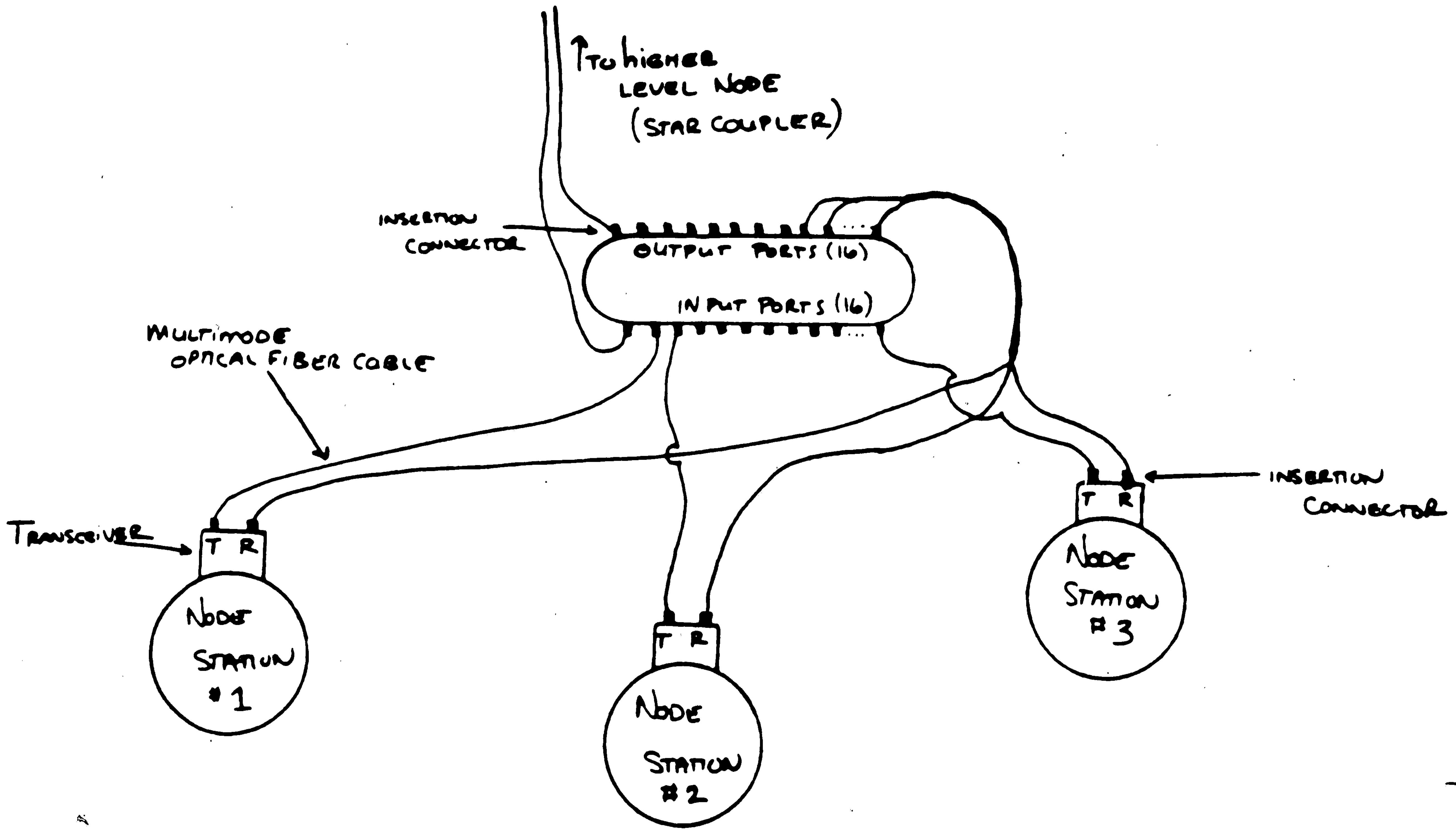

Figure 5. Functional Schematic of Physical Link

The following five sections provide an in depth analysis of the various components used to implement the transmission medium for the Mohler LAN. The first section characterizes multimode optical fiber with respect to optical power loss and bandwidth. The second, third and fourth section characterize optical star couplers, optical insertion connectors and transceivers respectively. The last section summarizes the performance characteristics of the entire physical link from analyses of the previous four sections.

2.1.1 Multi-Mode Optical Fiber Characterization

Optical fiber acts as a circular waveguide for specific wavelength ranges of optical radiation. It is useful as a communication medium because it can guide and direct optical information with very little power loss and be used for very large data rates. The optical fiber cable chosen for the Mohler network is a $62.5/125\mu m$ multimode optical fiber reinforced with an external Kevlar sheath[6]. Figure 6 shows a cross section of this multimode fiber optic cable.

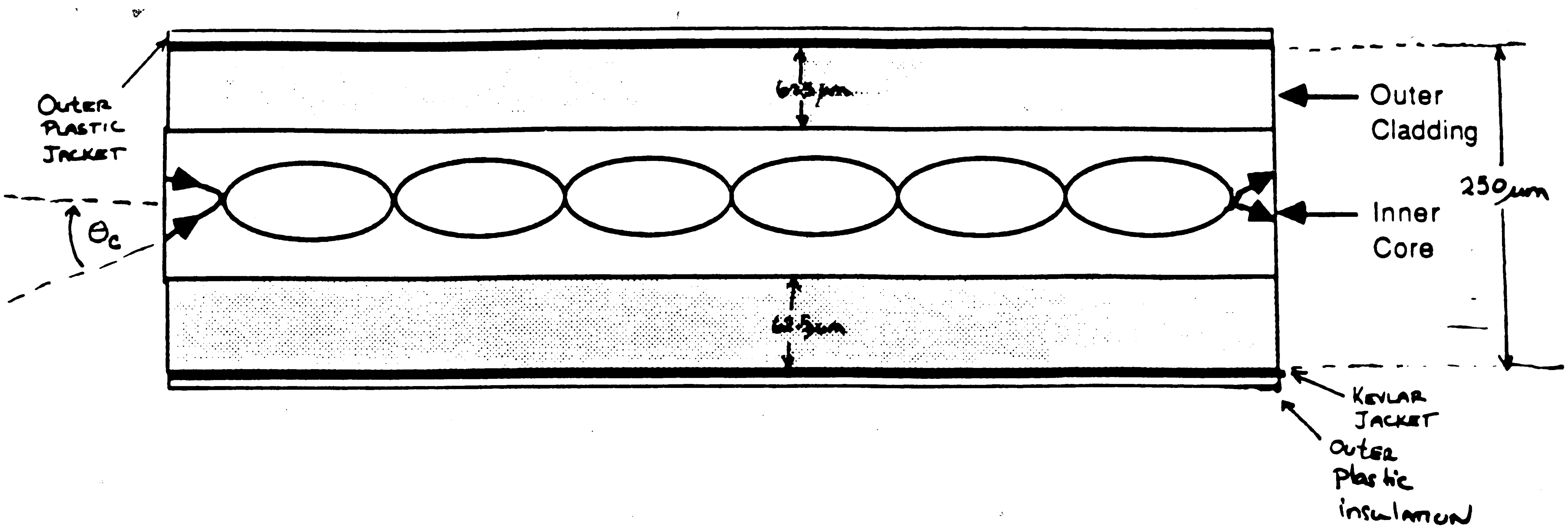

Figure 6. Multi-mode Graded Index Fiber[6]

Note the dimensions of the optical fiber. The inner core is $62.5\mu m$ in diameter; the outer cladding cover the inner core and is $62.5\mu m$ thick making its outer diameter $125\mu m$. A Kevlar jacket is wrapped around the outer cladding to provide some tensile strength in the fiber. The kevlar will take any axial stresses placed on the fiber. The outer surface of the cable is covered with a layer of plastic insulation. This prevents the fiber from being inadvertently scratched or bent.

Graded-index fibers offer multimode propagation in a relatively large-core fiber, coupled with low modal dispersion. The inner core has a varying index of refraction that decreases as you move out from the center of the core. It decreases until the outer cladding boundary is reached. At that point the index of refraction remains constant. This varying index profile has the effect of periodically focusing optical energy as it travels down the optical fiber. This is shown in figure 6 by a schematic of optical energy traveling down the inner core. The peak core material index of refraction is 1.4745, and the outer cladding index minimum is about two percent less. To a good approximation, the fiber index profile is modeled by the power law relationship that is shown in equation 1[7]:

$$n(r) = \begin{cases} n_1[1 - 2\Delta(\frac{r}{a})^g]^{0.5} & r<a \\ n_1(1 - 2\Delta)^{0.5} & r>a, \end{cases} \qquad \text{(Eq. 1)}$$

where $n_1 = 1.4745$ (maximum index of refraction for fiber core), $n_2 = 0.98\ n_1$ (index of refraction for cladding), r = distance from the core center, $a = 62.5\mu m$ (core radius), $\Delta = (n_1^2 - n_2^2)/2n_1^2$ and $g = 2$ for a parabolic index profile. Figure 7 graphically illustrates the index of refraction profile modeled by equation 2.

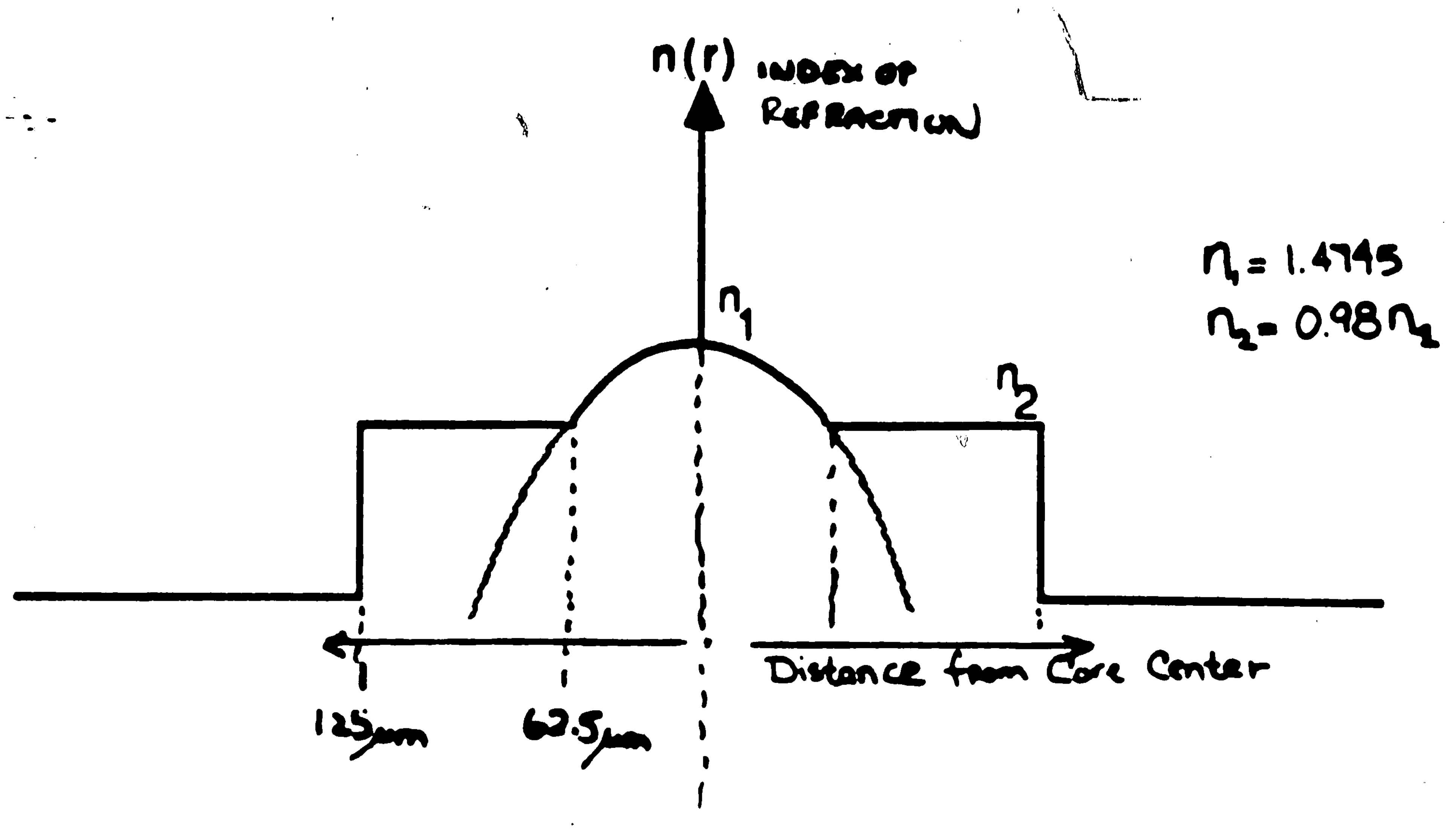

Figure 7. Structure and Index Profile of 62.5/125 Multimode Fiber[8]

Figure 7 shows core and cladding index of refraction profile for 62.5/125μm multimode optical fiber cable. The core center has a maximum index of n_1 and decreases as you move out from the center. This index levels out when the cladding region is encountered and is denoted by n_2.

2.1.1.1 Power Loss and its Relations to LAN Design

Power is coupled into the 62.5/125μm multimode optical fiber with a 0.275 Numerical Aperture (NA)[7]. The NA of a fiber is defined by equation 2:

$$NA = \sin\Theta_c \approx n_1 \, (2 \, X \, \Delta)^{0.5}, \qquad \text{(Eq. 2)}$$

and describes the maximum angle an optical ray is accepted into the core region. This is shown by Θ_c in figure 6. When an optical ray is accepted into the core region of a fiber, it propagates down the fiber axis. Power is lost when this optical energy propagates in the fiber, and is caused by two attenuation mechanisms — atomic absorption and dissipation. Atomic absorption is a term used to describe the energy absorbed by silica atoms when they are excited. Atomic dissipation describes the phenomenon where the silica atoms scatter light. This scattering phenomenon is caused by the thermal fluctuations in the material atoms during the solidification process. The cladding region of an optical fiber is usually more lossy than the core. The cladding region is not infinitely thick; it is about $62.5\mu m$ for our particular fiber selection. Some fraction of the optical energy mode fields traveling in the fiber are attenuated if they stray into the outer cladding region. This is more a problem when optical energy is misguided in the fiber. This is the case when an excessive NA is used. Absorption loss in multimode fiber is caused by these factors[6]:

Total power losses in $62.5/125\mu m$ fiber are typically wavelength dependent. Figure 8 illustrates this loss and wavelength dependence.[7]

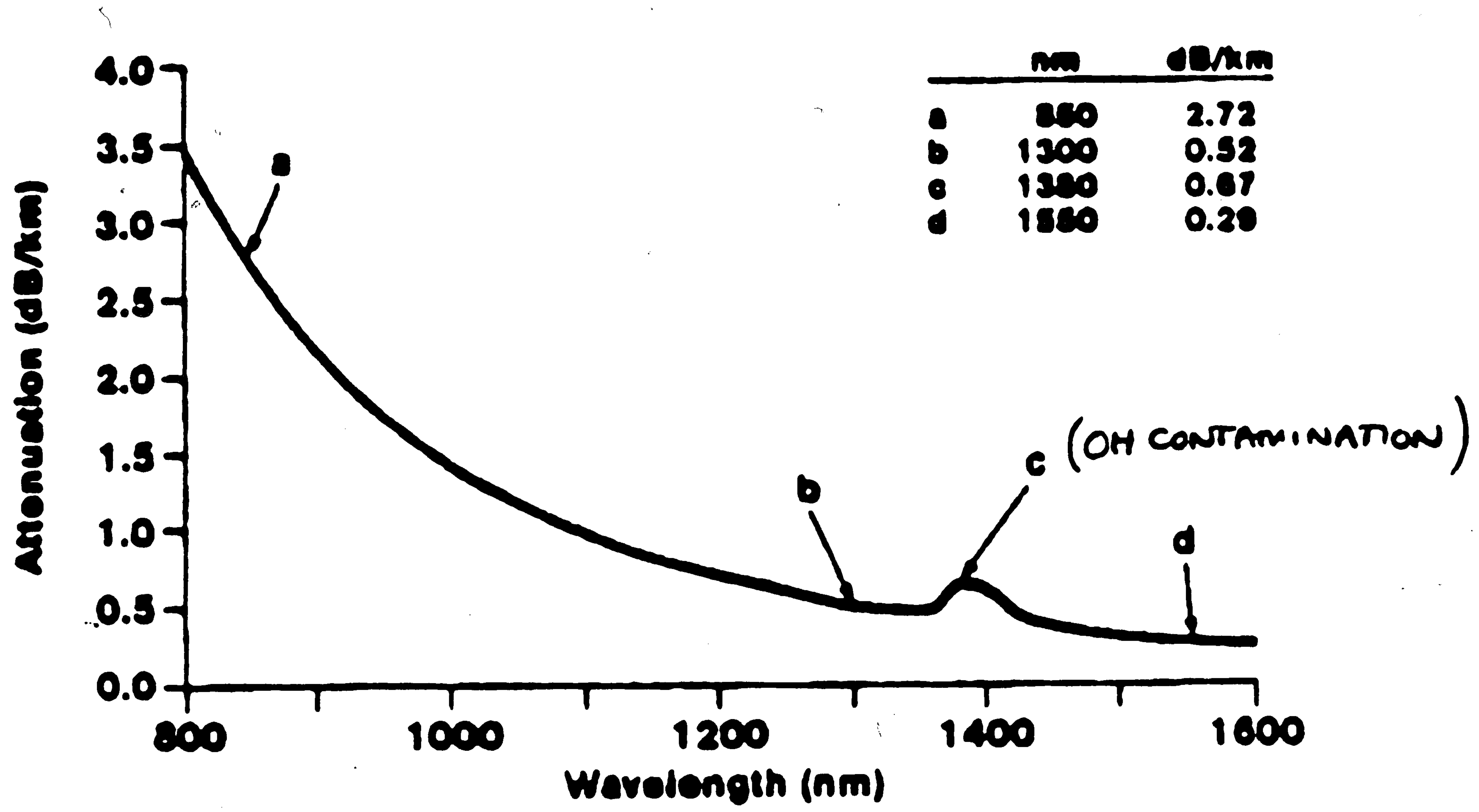

Figure 8. Loss Spectrum of 62.5/125 Multimode Fiber

The figure shows fiber attenuation from $800nm$ to $1600nm$ wavelength. Maximum losses occur in the smaller wavelength (ultra-violet) regions. This is denoted by arrow **a** in the figure. These excessive losses are a result of atomic absorption. Silica atoms absorb more energy from shorter wavelengths of optical radiation than they do from longer wavelengths. Fiber losses gradually decrease as the optical wavelength is increased. This is illustrated in figure 8 by arrows **b**, **c** *and* **d** *respectively. Most optical fibers have a peculiar increase in their attenuation profiles around* 1300*nm*. *This "hump" in the attenuation profile is shown at region* **c** and is caused by residual **OH** contamination in the silica glass. Its effects are similar to atomic absorption losses.

2.1.1.2 Bandwidth and its Relationship to LAN Design

Fiber bandwidth is a measure of the information capacity of the optical fiber and limits the rate at which data can be transmitted. Bandwidth is determined by analyzing an optical pulse as it travels down an optical fiber. An optical pulse has many different frequency components called optical modes. These modes travel at different rates along the fiber and arrive at the same point at different times when they are launched simultaneously; this is the case when launching an optical pulse on a fiber. Higher frequencies and longer propagation paths are more prone to this modal separation. An optical pulse will be distorted and *smeared* out after it travels for some distance along the fiber, thus putting an upper limit on the data modulation rate per unit length of fiber.

Measured bandwidth in multimode fiber depends primarily on two independent factors — Modal and Chromatic dispersion[6]. Modal Dispersion arises in multimode fibers because many modes propagate simultaneously. Imperfections in the graded-index profile cause these modes not to arrive at the same time. An ideal graded-index profile is designed so that shorter pulse paths have slower velocities than do longer pulse paths; thus, different modes arrive at the same point and time in the fiber. Modal dispersion is not a significant problem, though, at least with the multimode fibers now available. Their index profiles are very close to the ideal parabolic index profile discussed previously in equation 2. The parabolic index profile compensates for different modal velocities, by slowing up the faster components and speeding up the slower ones. Most modes travel as a group with a single velocity for reasonable cable lengths. This is why dispersion effects are smaller for graded-index fiber than any other type of multimode fiber.

Chromatic dispersion arises because optical sources do not emit a pure monochromatic light; they emit many different wavelengths of optical radiation simultaneously. Different wavelengths of light travel at different modal velocities down an optical fiber. The result ~~is~~ that different wavelength components of an optical pulse get spread out over time. Chromatic dispersion is responsible for most of the dispersive effects in modern multimode fibers. Its effect on 62.5/125μm multimode cable is modeled by equation 3:[7]

$$D_{fiber}(\lambda) = \frac{S_0}{4}\left[\lambda - \frac{\lambda_0^4}{\lambda^3}\right] \; ps/(nm \cdot km) \qquad \begin{array}{l} \lambda_0 = 1340nm \\ S_0 = 0.097ps \\ 750nm \leq \lambda \leq 1450nm, \end{array} \qquad \text{(Eq. 3)}$$

where S_0 equals the zero dispersion slope and λ_0 equals the zero dispersion wavelength of the multimode fiber. Chromatic dispersion characteristics of 62.5/125μm optical fiber are illustrated in the graph in figure 9[8][7].

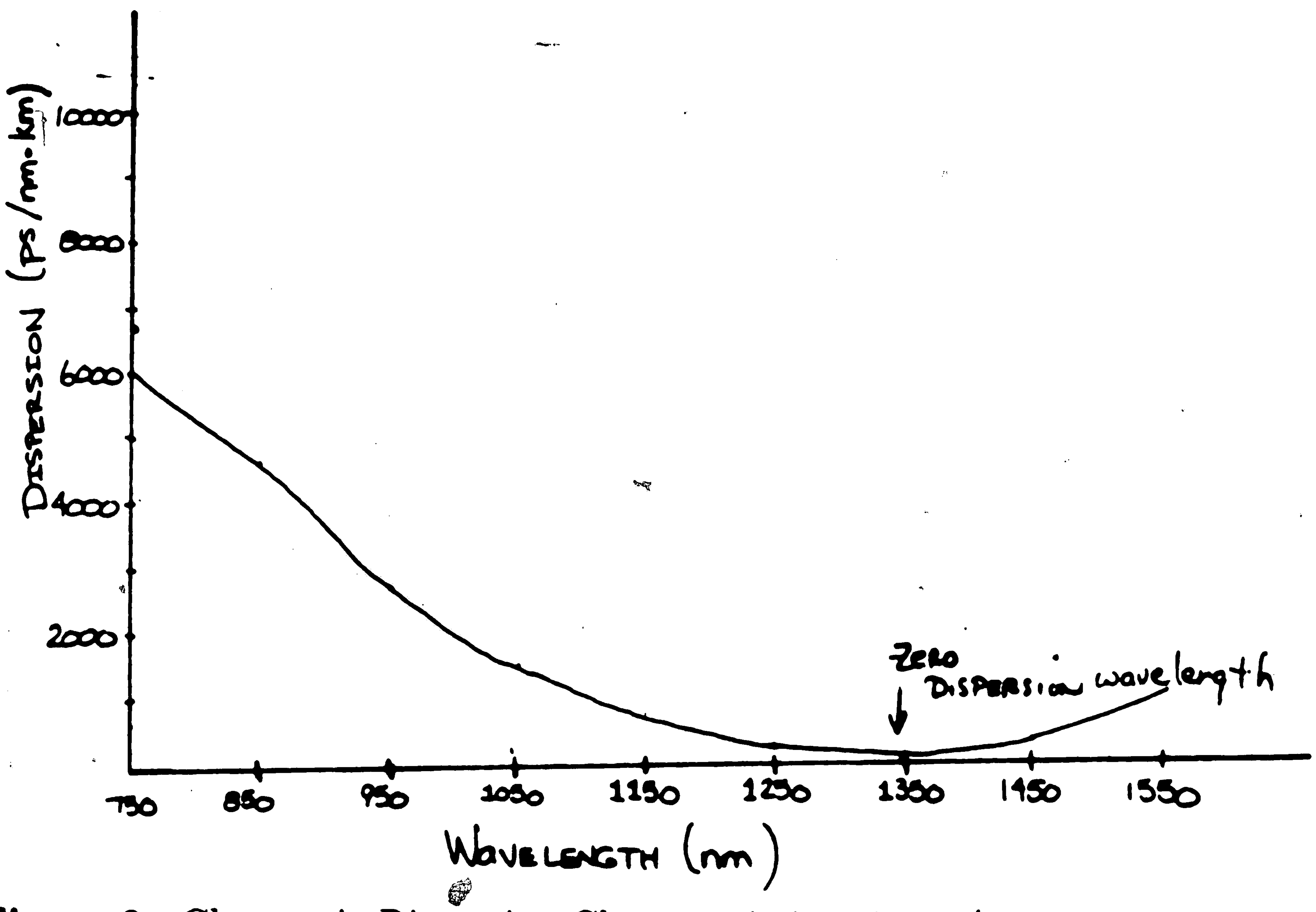

Figure 9. Chromatic Dispersion Characteristics of 62.5/125 Multimode Fiber

2.1.2 Optical Star-coupler Characterization

Optical star couplers are used to combine many optical signals together or divide a signal into many parts. An optical star coupler is composed of three regions — an input fiber region, a mixing region and an output fiber region. Optical energy is coupled into any of the input port fibers and is mixed evenly in the *mixing section.* The optical energy is then divided evenly among the output ports. This is shown is figure 10.

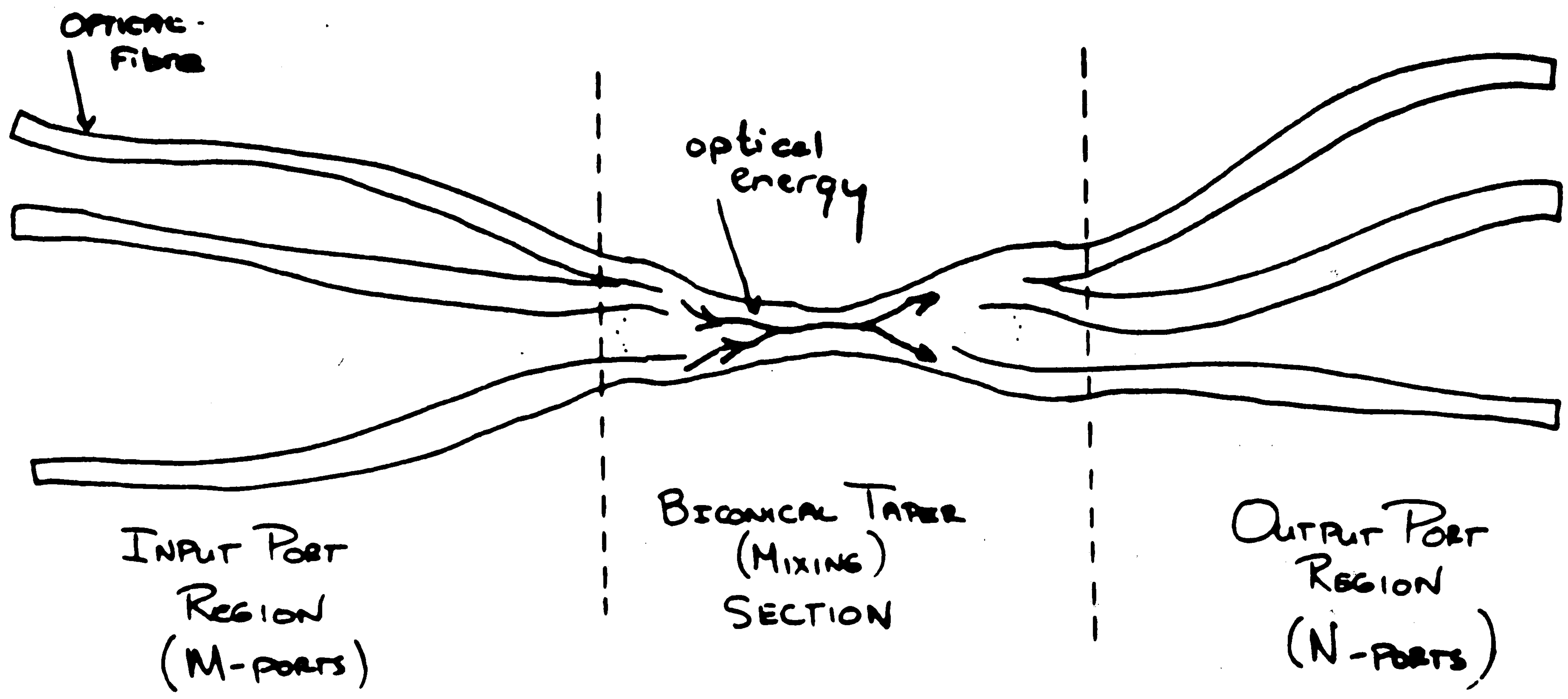

Figure 10. Biconical M X N Optical Star-coupler

The figure shows a biconical *MXN* optical star coupler. Couplers vary in the way they are fabricated. Biconical describes the manner in which the mixing section is formed. The mixing region is formed by fusing many optical fibers together at one point. More information on their construction is available in reference 9. Biconical taper couplers have the advantage over other types in that their output power level variations are minimized to some degree. Other types of couplers do not *mix* optical energy evenly. Some modes of optical energy from the input ports are not completely coupled into the cladding at the mixing region and subsequently remain coupled to a certain output fiber core[9]. The biconical taper coupler alleviates most of these output deviation by having all of the input modes of optical energy couple evenly into the cladding region of the mixing sections, and then, into the core regions of the output port fibers[10].

Star couplers are used in the Mohler LAN to combine and separate optical node signals. This is illustrated in figure 5 with a schematic of the physical link. Star couplers were chosen for the performance and reliability; they offer an efficient means to tap optical power out of and into a fiber optic link. They are passive mixing elements, where the optical powers from the input ports are mixed together and divided equally among the output ports. To better understand the performance of these couplers, it is necessary to look at how they couple and distribute optical energy. This is best analyzed by studying their port-to-port energy losses and bandwidth limitations.

2.1.2.1 *Optical Coupler Power Loss*

Biconical star couplers are used frequently with fiber optic LANs. Out of all the PFCs used to construct the physical link, optical couplers have the greatest effect on the performance of the link. Optical star couplers introduce a majority of the link loss and are the power *bottlenecks* for a LAN topology. Power loss in biconical taper star couplers is defined as the fraction of optical power lost in the process of coupling light from the input port to an output port. Input-to-input port power loss (L_{IO}) is given by equation 4:

$$L_{I-O}\ (dB) = 10 \log \left\{ \frac{\sum_{i=1}^{M} P_i}{N} \right\} + L_{c(input)} + L_{c(output)} \qquad \text{(Eq. 4)}$$

where P_i = *power launched into the* i^{th} *port*
M = *number of input ports*
N = *number of output ports*
L_c = *port insertion loss*

Insertion connectors on the coupler ports introduce an additional loss term into the power loss relationship. We assume that each port connector introduces an average loss given by L_c. The total input-to-output power loss relationship (L_{IO}) is modified accordingly.

It is also important to characterize a star-coupler by its ability to guide light directionally from its input ports to its output ports. This ability is quantitatively measured in terms of an input-to-input port isolation loss. An optical signal is coupled into an input port of a star coupler, then the remaining input ports are measured for any output energy. An ideal star-coupler will have no power coupled out of the other input ports. In other words, the coupler will have a extremely high isolation loss[11].

Equation 5 models isolation loss (L_{isol}) for an MxN coupler. *Note that isolation loss is measured between any two input ports.*

$$L_{isol} = 10 \log \frac{(1-R)(R)}{M^2}\left[\frac{n_{cladding}}{n_{core}}\right]^2 + 2L_{c(input)} \qquad \text{(Eq. 5)}$$

where

M = *number of input ports*
$n_{cladding}$ = *minimum index of refraction* for *cladding*
n_{core} = *maximum index of refraction* for *core*
R = *effective reflection coefficient* for *coupler mixing region*
L_c = *input port insertion loss*

Equation 4 was obtained by fitting isolation loss data from various NXN couplers[2]. The equation assumes that the coupler mixing region will not couple all input power into the output ports. This is quantitatively measured by a mixing region *reflection* coefficient denoted by R. Core to cladding power coupling is described by the $\left[\frac{n^2_{cladding}}{n^2_{core}}\right]/M^2$ ratio. Table 1 lists input-to-input port isolation and input-to-output port losses for three types of MXM star couplers supplied by AMP Incorporated. The information in the table shows loss data for $4X4$, $8X8$ and

2. Isolation data was supplied by *AMP Incorporated* for $4X4$, $8X8$ and $16X16$ biconical taper optical star couplers.

16X16 star couplers. Five couplers of each type were measured for input-to-input port isolation and input-to-output port losses; The loss measurements for each type of coupler were then averaged together. The table shows average measured losses for each coupler type under the column marked *measured.* The loss data under the columns marked *model* represents predicted losses for the three different types of star couplers. Equation 5 is used to calculate the predicted input-to-input port isolation for the AMP *MXM* couplers. The constants used in equation 5 to model the AMP star couplers are R=0.30, n_{core}=1.4745, $n_{cladding}$=0.98n_{core} and L_c=0.5. Equation 6 is used to calculate the predicted input-to-output port loss for the *MXM* couplers. The constants used in this equation to model the AMP star couplers are $L_{c(input)}$ and $L_{c(output)} = 0.5dB$.

Coupler Type	L_{isol} (measured)	(model)	L_{IO} (measured)	(model)
4 X 4	23.00	19.99	6.72	7.02
8 X 8	25.95	26.02	10.32	10.03
16 X 16	28.50	32.04	13.70	13.04

Table 1. Calculated -vs- Actual Power Loss Values

Figure 11 shows a cross section of a star coupler modeled after those supplied by *AMP Incorporated.* The coupler itself lies in a sealed rectangular mount at the rear of the coupler mounting box. The input fibers connect the top row of ports to the left hand side of the star coupler mount, and the output fibers connect the bottom row of ports to the right hand side of the star coupler mount. Insertion connectors are used to terminate the input and output ports of the coupler. These connectors provide optical connections to the outside world.

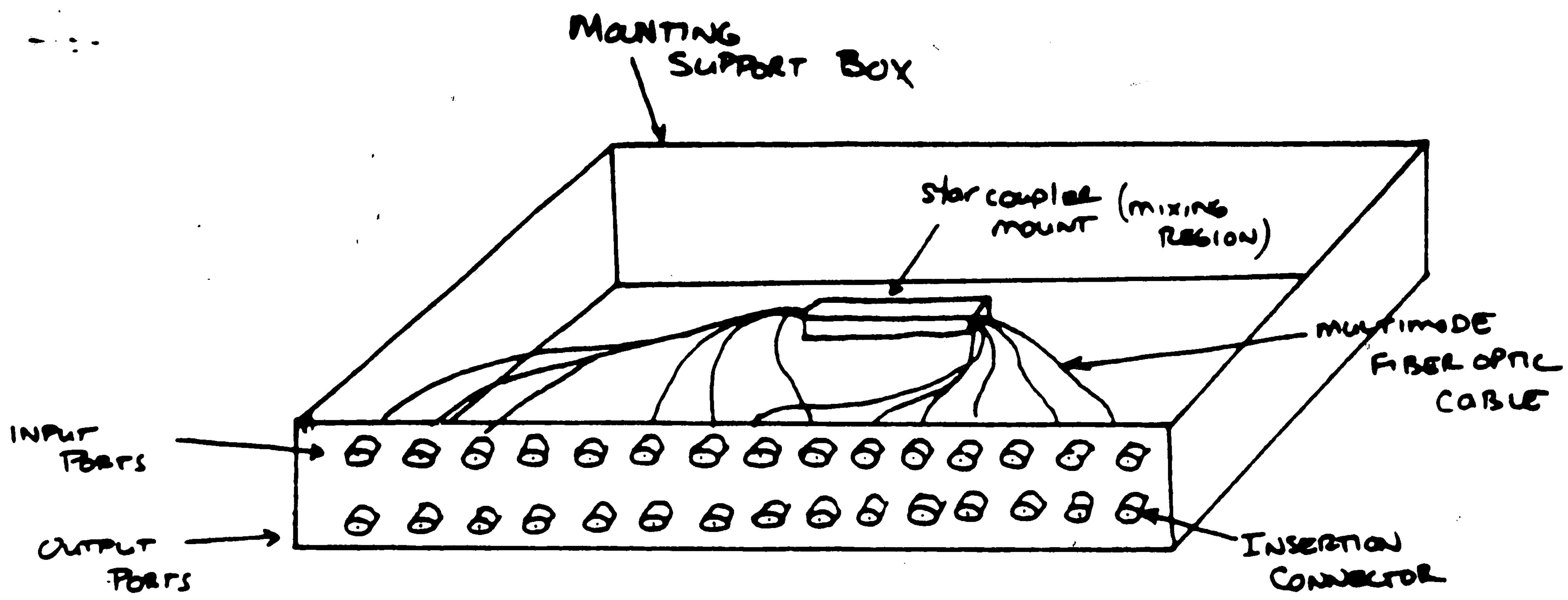

Figure 11. Cross-section of Operational Star-coupler

2.1.2.2 Bandwidth and it Limitations on LAN Design

Optical star couplers are the limiting factor for the physical link bandwidth. They are made by fusing together multimode optical fibers. It is reasonable to assume that they have bandwidths approaching that of the fiber used to create them. This is approximately correct. Biconical taper star couplers available today have excellent dispersion characteristics. Their dispersion characteristics are slightly less than the fiber used to create them. This is caused by imperfections in the biconical taper (mixing section). Uniform tension on the coupler leads during the fusion process creates a non-uniform taper and causes different optical energy modes to be coupled unevenly in the mixing section, giving preference to some cladding modes. This places an upper limit on effective bandwidth of the coupler. Equation 6 is an empirical relationship for coupler dispersion and describes the upper bandwidth of a star coupler (see equation 2 for a fiber dispersion relationship).

$$D_{coupler}(\lambda) = 0.95\, D_{fiber}(\lambda) \qquad \text{(Eq. 6)}$$

$$750nm \leq \lambda \leq 1450nm,$$

AMP $16X16$ optical star couplers were measured for their maximum bandwidth and compared against a one meter section of the multimode fiber used to create them. It was found that the coupler dispersion is directly proportional to values of fiber dispersion for any wavelength in the range $750nm \leq \lambda \leq 1450nm$. In our case, the proportionality constant was found to be 0.95.

2.1.3 Optical Connectors

Practical system considerations require low loss, connect-disconnect, connectors. These connectors find their use in the connection of distribution system components such as star couplers, optical fiber, and transceivers (LED sources and photo-detectors). Connect-disconnect connectors fall into a broad category of mechanical splices known has insertion connectors. They should offer the following features to the LAN physical link:

- They can provide a repeatable low-loss connection (0.1 to 0.5 dB)
- They are simple to install
- They have a long lifetime if properly installed
- They are maintenance free over their lifetime
- They do not limit fiber bandwidth if properly installed
- They have a low sensitivity to environmental conditions such at dust, temperature and moisture

Figure 12 shows a cross-section of a typical insertion connector, like those used in the Mohler LAN.

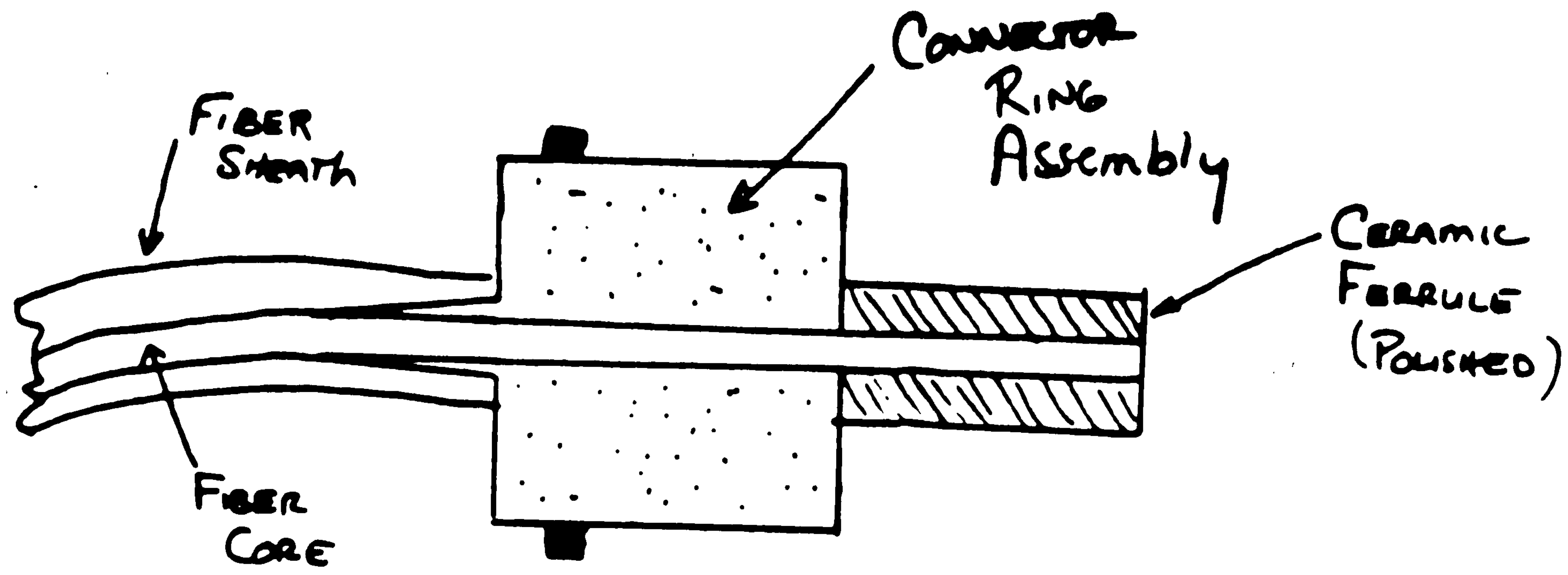

Figure 12. Cross-section of a Typical Insertion Connector

The figure showsa multimode optical fiber mounted in a connector barrel. The fiber core is epoxied into the ceramic ferrule at the tip of the connector. The fiber core surface is cleaved, polished down to the ferrule surface and held in place by the connector ring assembly. Figure 13 shows two St-type insertion connectors mated in an alignment sleeve. The connector ring assembly is used here to securely fasten the connector barrel to the alignment sleeve and prevent it from coming loose.

If properly installed, mechanical insertion connectors enhance a LAN design by allowing its system components to be connected repeatedly, with low loss. The connectors are characterized by having low loss and negligible dispersion effects on the LAN. The following two sections review these characteristics and outline their effects on LAN performance, with the first section reviewing connector loss and the second section reviewing connector bandwidth limitations on the LAN physical link.

2.1.3.1 *Connector Power Loss*

Power loss with insertion connectors depend on parameters controlled by the manufacturer, and to some degree, on the connection technique employed[12]. Power attenuation is mainly owed to parameters extrinsic to the fiber, such as mechanical alignment and fiber end-surface smoothness. The mechanical alignment is dependent on the interconnection technique used, while the smoothness is dependent on the polishing technique used.

Mechanical alignment is probably the most important element for proper connector operation. The fiber is routed through the connector barrel and permanently mounted with epoxy. Once the epoxy is applied and cured, the fiber is cleaved, and subsequently polished to provide a defect-free surface parallel to the barrel end-face. Fiber connection is accomplished by butting two connector end-faces together so that one fiber is lined up with the other on its axis. This is illustrated in figure 13 with two ST-type connectors connected with a precision alignment sleeve.

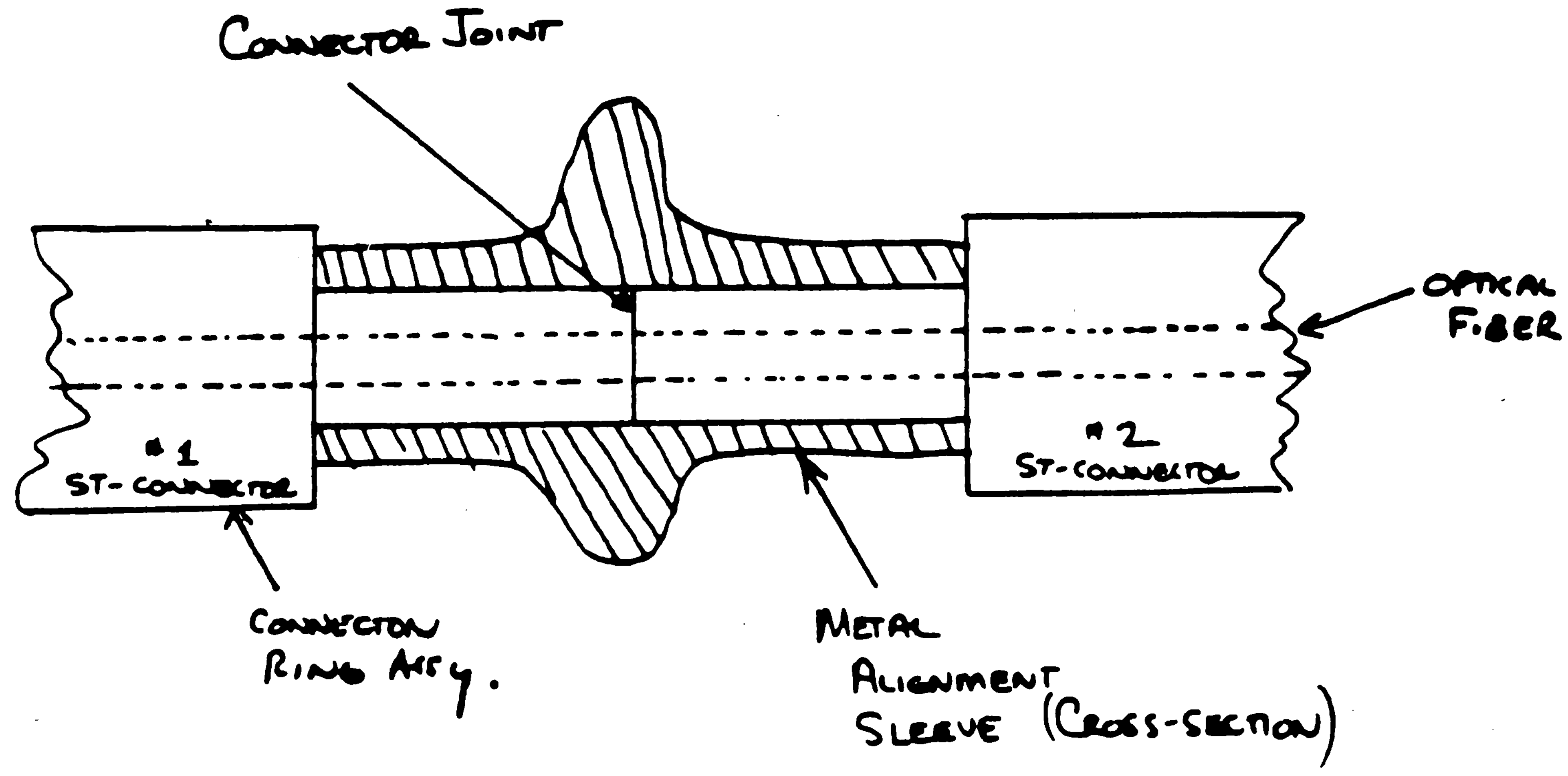

Figure 13. ST-type Connector Alignment

The alignment sleeve is used to guide the two connectors so that they line up on axis and so their end-faces touch each other. The connectors are help in place by connector ring assemblies located in the mid-section of the connector body. This is shown in the figure.

Problems arise when the fibers are not aligned on axis or there is significant separation between the fibers of the connector joint. Optical energy losses result from mechanical misalignment of the connectors because the radiation cone of the emitting fiber does not match the acceptance cone of the receiving fiber. The magnitude of this energy loss depends on the degree of misalignment. Three types of misalignment occur. They are *longitudinal separation, angular misalignment* and *axial displacement*, all of which are depicted in figure 14[13].

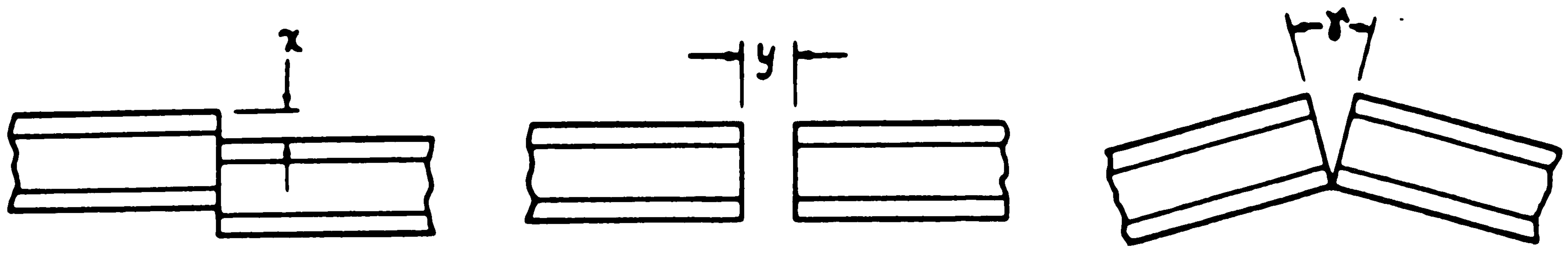

Figure 14. Types of Mechanical Misalignment Between Two Connector Joints

Longitudinal separation occurs when the two fibers lie on the same axis but are separated by a distance y. Axial separation occurs when both fiber end-faces are touching in the same plane but are displaced vertically from each other by a distance x. Angular displacement occurs when both fiber end-face places are separated by an angle of γ.

The most common misalignment occurring in the field is axial displacement, especially with the insertion type connectors used today. Insertion type connectors are mated with alignment sleeves. The connectors must fit these sleeves with precision tolerances to avoid any alignment error. It is assumed that the insertion connectors are precision made with concentric barrel bore and ferrule.

Axial displacement causes the greatest optical power loss of any other type of displacement with insertion connectors currently available. The axial offset (x) reduces the overlap area of the two fiber end-faces. This is illustrated in figure 15.

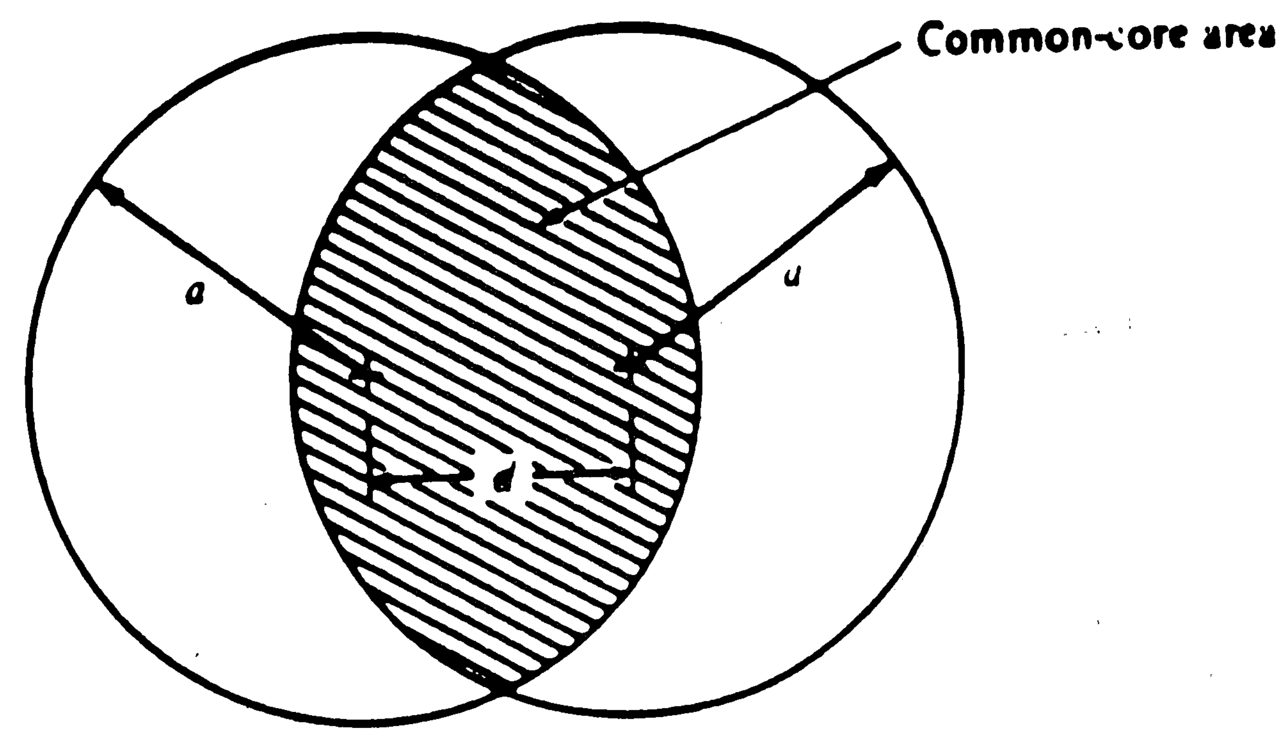

Figure 15. Axial offset of two fiber end-faces

Figure 15 shows a cross-section view of the connector joint of two mated insertion connectors. Only the fiber cores are shown. It is assumed that this is 62.5/125μm graded index optical fiber. The inner core diameter, denoted by a, is 62.5μm. Axial offset is given by d and ~~is~~ measured in microns. Because the numerical aperture is non-uniform across the face of graded-index fibers, the power transmitted across a connector joint is not a simple ratio of overlap areas[13]. The relationship for power transmitted must take into account the varying NA of the graded index fiber. After taking this into account, we come up with equation 7.

$$P_T = \frac{2}{\pi} P \left\{ arccos\left\{ \frac{d}{2a} - [1 - (\frac{d}{2a}^2)]^{1/2} \frac{d}{6a} (5 - \frac{d^2}{2a^2}) \right\}\right\}, \quad \text{(Eq. 7)}$$

Equation 7 describes the power transmitted through the connector joint as the axial offset x is varied from 0 to $2a$, and in the case of 62.5/125μm multimode fiber, the offset is varied from 0 to 125μm. We assume that P_T is the power accepted by the receiving fiber, and P is the power launched from the transmitting fiber.

It is important to polish the end-faces of the fiber connectors correctly because improperly polished connectors scatter light at the connector joint. Improper polishing procedures can cause two types of connector end-face damage. This first type is described by an improperly cleaved fiber end-face, while the second is described by a chipped or ragged end-face.

Figure 16 shows an improperly cleaved fiber end-face. This is caused by using a dull cleaver on the fiber or by scribing the fiber at an angle that is not perpendicular to the fiber axis. Defects such at this cause the connector end-faces to not butt securely against each other, thus leaving a significant air gap at the connector joint. Optical radiation escapes from the lip and out through the air gap.

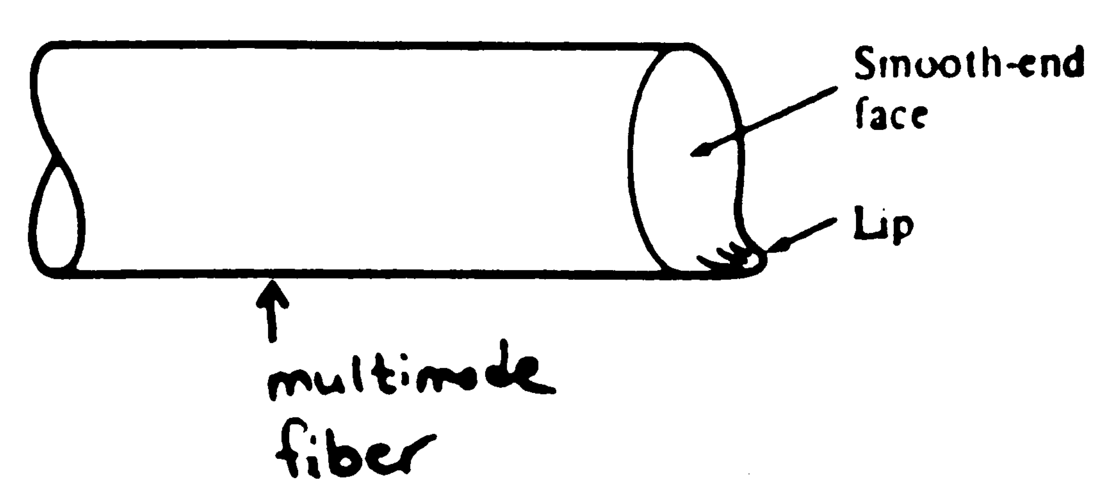

Figure 16. Improperly Cleaved Fiber End-face

Figure 17 shows a chipped or ragged fiber end-face. This is caused by breaking the fiber off at the connector surface before the epoxy dries or is caused by improper polishing procedures. Excessive force on the polishing film or using a too coarse grit can cause the fiber surface to become chipped or ragged. Optical energy is lost because the hackled surface shown in the figure is unable to guide power along the fiber axis. Power lost at the connector joint, because the two end faces at a connector joint are not butted properly.

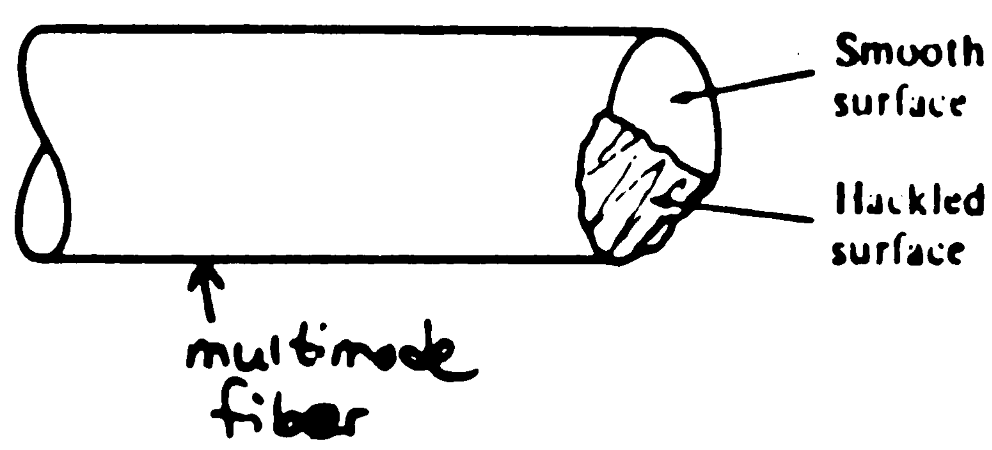

Figure 17. Chipped or Ragged Fiber End-face

2.1.3.2 Connector Dispersion Effects

Only qualitative analyses can be made of the effect insertion connectors have on optical fiber bandwidth. A properly prepared connector joint will not decrease the available bandwidth of the fiber. Any changes caused by the connector joint will be marginal, if any. Grossly misaligned or pitted connector joints filter out some optical power modes as they pass through the connector, but modal filtering also has a marginal effect on the modal dispersion component of obtainable bandwidth.

2.1.4 Transceiver Operation

A typical transceiver consists of an optical detector and optical source pair with additional amplification and equalization circuitry to process electrical signals. A functional schematic is included in figure 18 for reference.

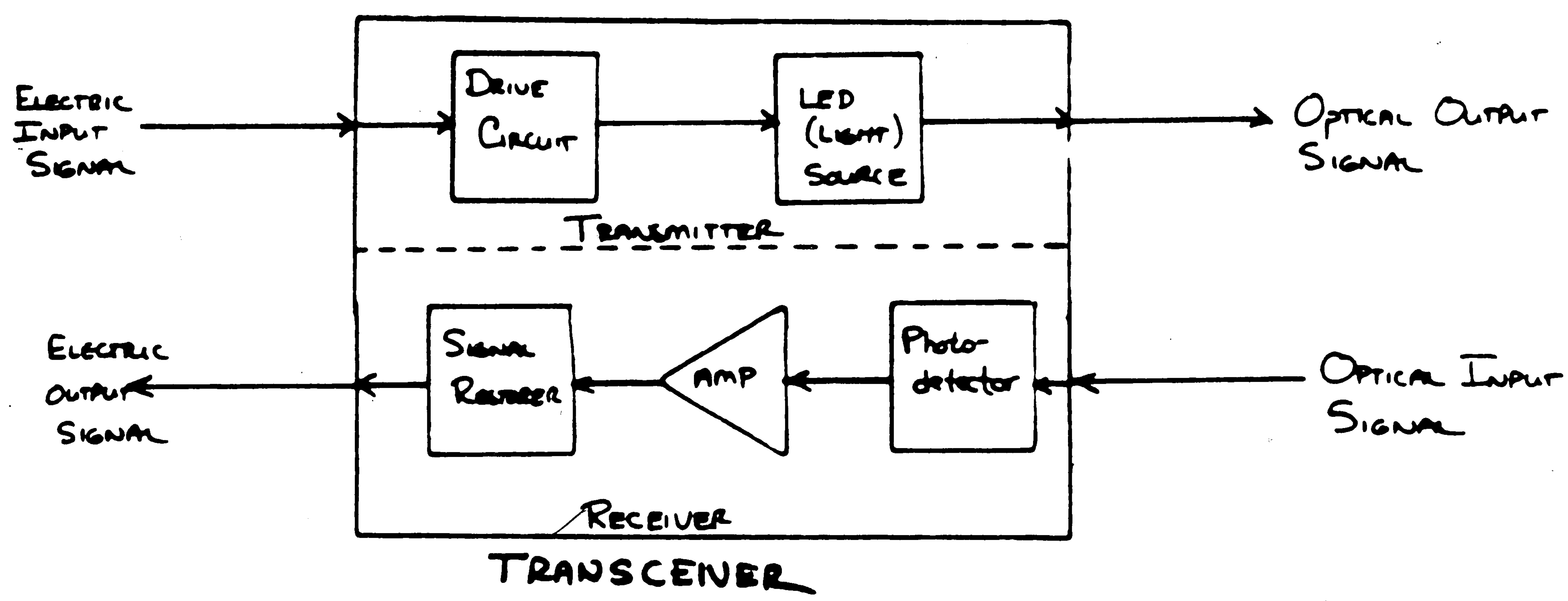

Figure 18. Functional Schematic of Optical Transceiver

Figure 18 is divided into two sections. The top half of the schematic contains the transmitter with its *drive circuitry* and *optical energy source (LED)*. The transmitter is used to convert electrical signals into optical pulse information. An electrical data signal enters the drive circuit inputs. The drive circuit modifies the electrical signal so that it can bias the LED correctly and produce an optical output signal. The optical output signal from the LED should represent the same data that entered the electrical input of the drive circuit.

The lower portion of figure 18 contains the receiver with its *photodetector, signal amplifier* and *signal restorer*. The receiver is used to convert optical signals back into electrical information. An optical signal is guided into the photodetector. The photodetector produces an electrical signal that is proportional to the intensity of incident optical signal. This electrical signal is fed into an amplifier and then a signal restorer, where the data information is extracted. The electrical output signal from the signal restorer should represent the same data that entered the optical input of the photodetector.

The transmitter section of a transceiver is described by the schematic in figure 18. Transmitters are fairly simple to design and build. Receivers on the other hand are a bit more complicated. Figure 19 provides details of an equivalent circuit used model a typical optical receiver.

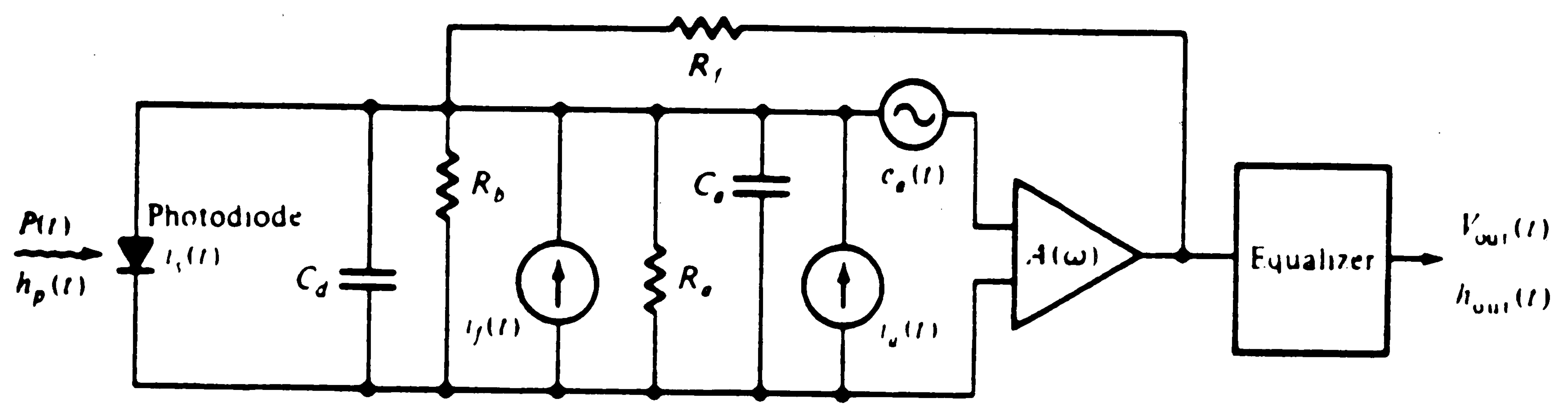

Figure 19. Typical Receiver Cross-section

The figure shows the photodiode with its equivalent junction capacitance denoted by C_d. The amplifier is a negative feedback drive circuit. It is very sensitive to current fluctuations in the photodiode. Its sensitivity is adjustable by changing the values of R_a, R_b and R_f respectively. The output of the amplifier is fed into the input of an signal restorer or equalizer, where the equalizer ensures that the electrical signal has the proper voltage or current levels. This ensures the data is interpreted correctly.

Transceivers are the active components of the LAN physical link. Within the constraints of the PFCs, the transceivers determine how much optical power is sent over the physical link and the rate at which data is sent. The optical transmitter must be able to send data over the transmission media at power levels greater than that absorbed by the PFCs in the physical link and still be detectable with a receiver. The receiver must be able to accept optical data at modulation rates determined by the transmitter. This modulation rate is constrained to be less than the physical link bandwidth. The following two sections discuss transceiver power budget (operation power level) and bandwidth, respectively.

2.1.4.1 Transceiver Power Budget

Transceiver *power budget* describes the difference between the absolute power level launched by transmitter and minimum detectable power level at the receiver. The difference in power levels must be greater that the losses encountered in the physical link between any two transceivers in order for the LAN to operate properly[13]; this includes sequential loss contributions from the optical fiber, connectors and optical star couplers. The transceivers available for LAN applications can operate over a wide range of power levels. LED/p-i-n transceivers are available with a dynamic range of 26dB of power. It is common to find LED transmitters that have absolute power outputs of -3dBm and p-i-n receviers that have minimum detectable power levels of -29dBm. This is an important consideration for determining a LAN's physical topology. A large transceiver dynamic range permits much more flexibility in the physical link design. In general, a larger dynamic range in transceiver power will allow the LAN to support greater serial losses in its physical link (ie. losses caused by longer fiber optic cables, larger star coupers, more connectors, etc.)

2.1.4.2 *Transceiver Bandwidth*

The bandwidth limitations of a transceiver are different from the bandwidth limitations of PFCs. One major consideration with transceiver frequency response is the ability of the optical receiver to respond to variations in incident optical power intensity. Another consideration with transceiver frequency response is the ability of the optical transmitter to provide an optical output that is linear with respect to the electrical signal driving it. Optical sources are driven into saturation easily and are prone to temperature and other instability effects. With proper equalization and amplification circuitry, receivers can be fabricated with reasonable frequency response. Typical LAN transceivers incorporate LED sources and p-i-n photodetectors. Proper electrical circuitry permits these transceivers to operate at data rates as high as 500M baud.

The four main mechanisms that limit the frequency response of a transceiver are[8]:

- The finite diffusion time of carriers produced in the *p* and *n* regions of the receiver photodetector and transmitter LED. Material choice affects what frequency the system components are optimized for. LEDs are usually made from GaAs or InP. These materials have very small carrier diffusion times (less than a nanosecond). Photodetectors are traditionally made from Silicon or Germanium; these materials have carrier diffusion times that are a magnitude larger than either GaAs or InP. Photodetectors made from these materials have slower response times than LEDs and are not suited for high speed transceivers. It is necessary to use more elaborate materials for photodetectors in order to match the high speed performance of LEDs available today. These new materials include InAs and InSb.

- The shunting effect of the signal current by the junction capacitance of the LED or photodetector. This places an upper limit on the intensity modulation frequency of the junction. This is empirically modeled by equation 8,

$$\omega \approx \frac{1}{R_e C_d}, \qquad \text{(Eq. 8)}$$

where R_e and C_d are the equivalent resistance and parallel junction capacitance respectively.

- The bandwidth response of the receiver amplification circuitry. Bipolar amplifiers tend to have higher bandwidth-gain products, while their FET counterparts have lower products.
- The bandwidth of the transceiver equalization circuitry.

Figure 20 illustrates typical quantum efficiencies for various LED and photodiode materials. Quantum efficiency is directly related to transceiver power efficiency.

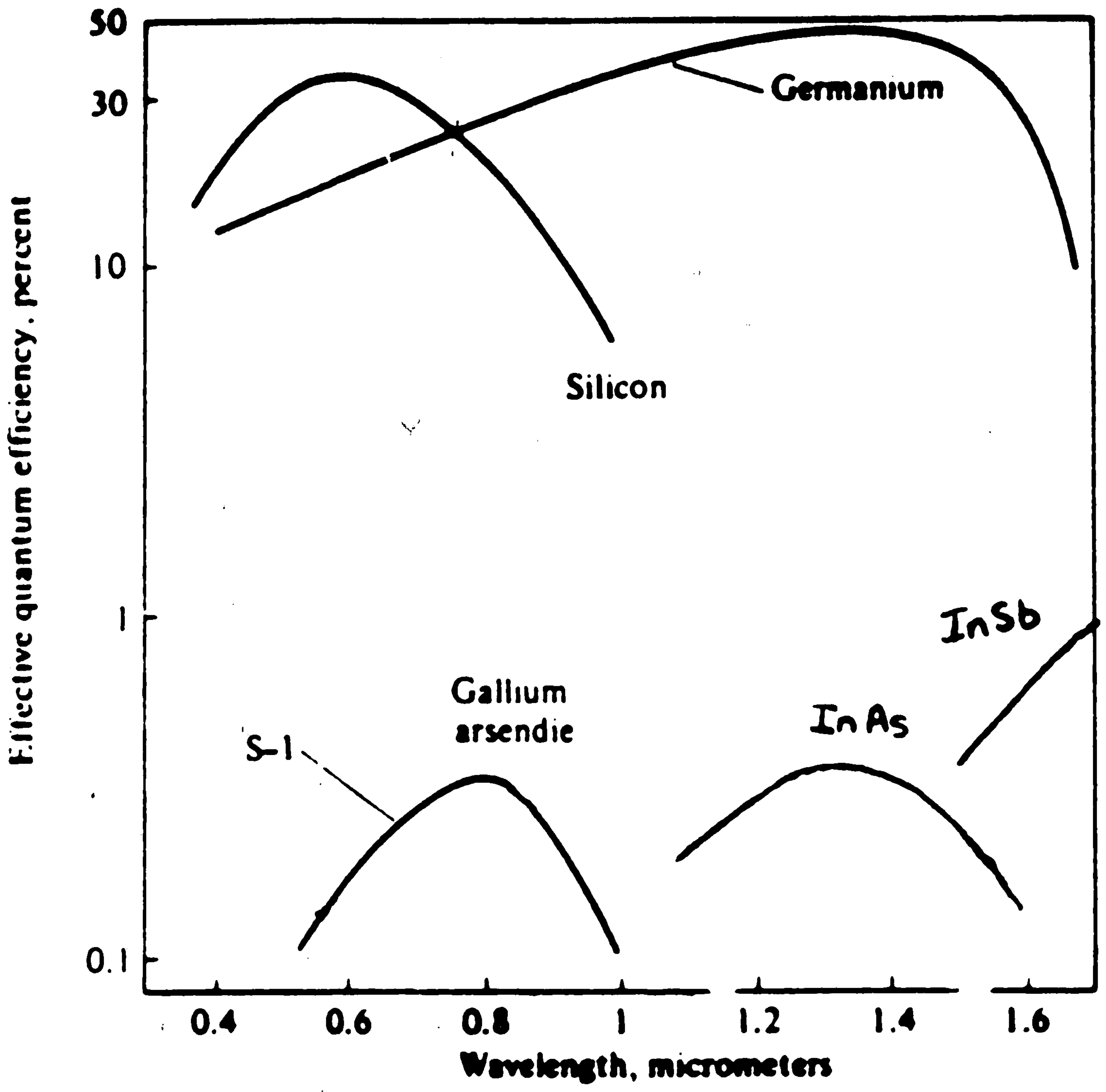

Figure 20. Comparison of LED and Photodetector Efficiencies and Wavelength

The figure shows five commonly used materials to construct either LEDs or photodetectors. Germanium and Silicon have large efficiency ratings over a wide range of wavelengths, but have poor carrier diffusion times when they are compared to the more exotic materials. Medium speed transceivers (0-50M baud) use Ge or Si p-i-n photodetectors, because they are reliable and economical. High speed transceivers (> 50M baud) need to use faster devices made from the other materials. These materials have shorter carrier diffusion times and produce devices that can operate at higher data rates.

2.1.5 Overall Technical Performance

PFCs and active system components were chosen for the Mohler LAN project with the following goals in mind:

- Provide an architecture that is expandable.

- Provide network bandwidths that are not limited by the transmission medium. Future bandwidth upgrades will require that faster transceivers be used on the physical link. The physical link is made entirely of passive components and has a bandwidth that nearly matches that of multimode fiber[14]. Table 2 contains fiber bandwidth data. The data was taken from the 62.5/125μm multimode fiber used for the Mohler LAN.

Wavelength	Bandwidth
830nm	360MHz
1300nm	550MHz

Table 2. Measured Bandwidth of Mohler LAN Transmission Medium

The data in table 2 was taken with a Tektronix optical power source and detector that has a 1GHz data modulation capability.

The overall power budget of the physical link consists of the total serial loss between the optical transmitter and receiver. This includes losses from optical insertion connectors, optical fiber, and optical couplers. The optical transmitter must have a power output larger than the total link loss between the transmitter and receiver (see equation 3). The received output from the transmitter must also be strong enough to be detected by the optical receiver. To ensure that the received signal is strong enough, a system power margin is added to transmitter power output. The difference between the maximum power output of the transceiver and minimum detectable optical power input of the transceiver determines the overall LAN power budget. Equation 9 shows the different components of a LAN power budget.

$$L_B = P_{Total\ Couplers} + P_{fiber} + P_{connectors} + P_{system\ margin} \qquad \text{(Eq. 9)}$$

The physical link loss budget (L_B) consists of the maximum optical power losses ($P_{T\ Couplers}$) due to optical couplers between any transmitter and receiver, the maximum fiber losses (P_{fiber}) between any transmitter and receiver, the maximum optical connector losses ($P_{connectors}$) between any transmitter and receiver, and a system power margin ($P_{system\ margin}$) for safety[13].

Maximum cable lengths found between any transmitter and receiver in the Mohler Building are 100 meters because of the building size. The maximum fiber losses (P_{fiber}) are therefore equal to 0.3dB. The insertion connection used in the Mohler LAN have an insertion loss of 0.3dB. The LAN has a maximum of six connectors between any transmitter and receiver. This includes the two connectors present in the node station outlet. The maximum connector loss ($P_{connector}$) is equal to 1.8dB. The $16X16$ optical star-couplers used on the LAN have an average input-to-output port loss of that is given by equation 3. The total coupler loss ($P_{Total\ Coupler}$) is equal to 14dB by evaluating equation 3 for 16 ports. The transceivers chosen for implementing the 802.3 LAN protocol have an available 26dB power budget. By equating this value with total link loss budget L_B we find that the Mohler LAN has an 9.9dB system power margin ($P_{system\ margin}$). The link loss budget is illustrated in figure 21.

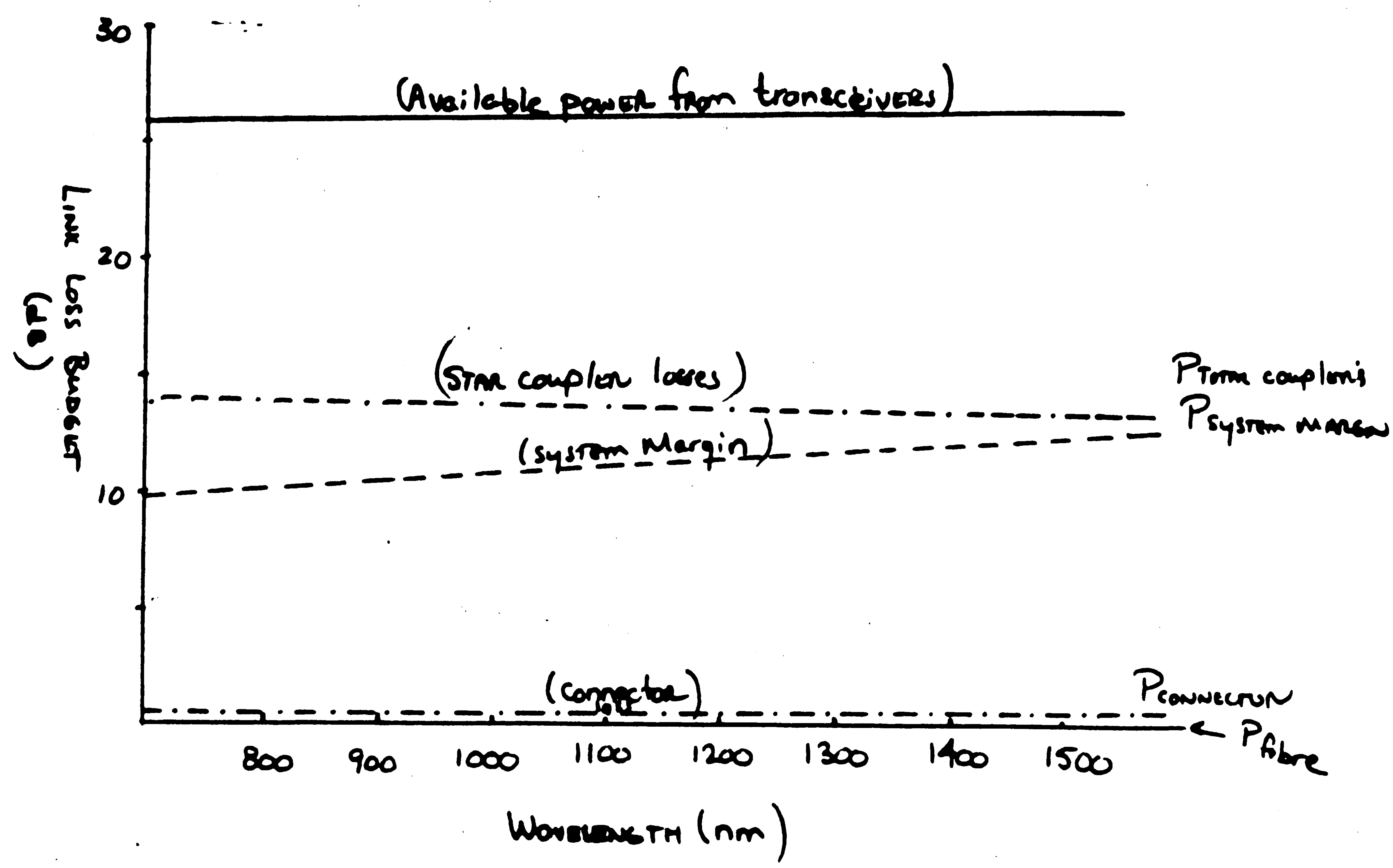

Figure 21. Link Loss Budget for Mohler LAN

Please refer to Appendix A for a schematic of the LAN layout. The layout shows relative locations for optical star couplers, optical fiber and node station points.

2.2 LAN Protocols

This section explains how the IEEE 802.3 and 802.4 protocol specifications are organized, and how they are implemented on the Mohler LAN transmission medium. A protocol specification is best treated as an ordered set of functional requirements. Each set or layer performs a specific function and passes its outputs to the next higher layer. Organized properly, a protocol is treated as a structured set of tasks that implements the LAN's communication function[2]. The various elements of this set are explained clearly with the ISO Model Reference to Open Systems Interconnection, as suggested by figure 22.

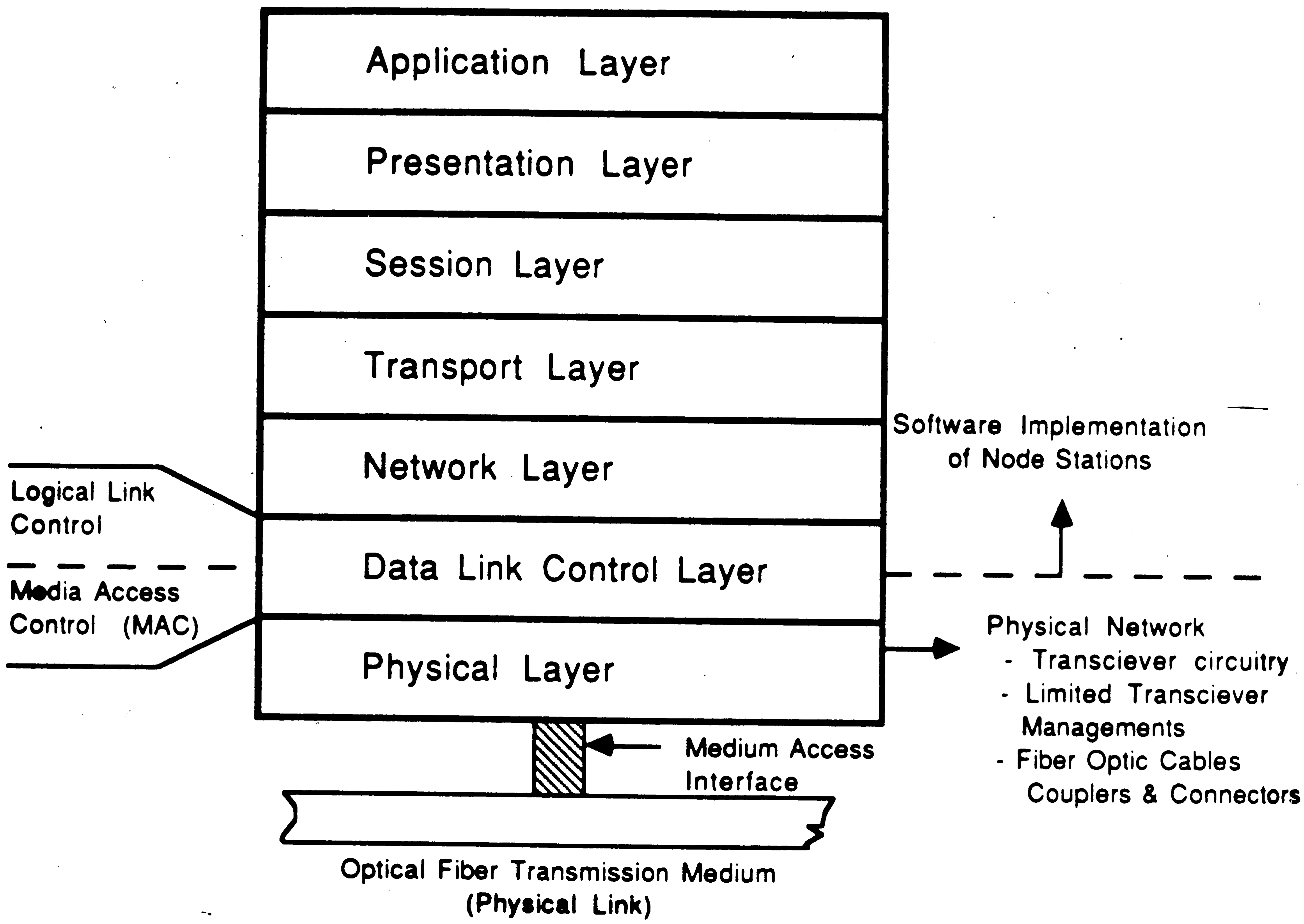

Figure 22. ISO Model Reference to Open Systems Interconnection

The ISO model depicts a layering technique where communications functions are partitioned into a vertical set of layers. Each layer performs a related subset of functions required to communicate with another system. More primitive functions are left to the next lower layer and are subsequently concealed from higher layers. The ISO Model layers are defined so that changes in one layer do not affect the implementation of other layers. This is an important criterion for evaluating a LAN protocol suite.

The ISO Model is composed of seven layers — the Physical Layer, Data Link Control (DLC) Layer, Network Layer, Transport Layer, Session Layer, Presentation Layer and Application Layer. This is reflected in figure 22. The IEEE 802 family of protocols deal primarily with functions described in the two lowest layers in the ISO Model— the Physical and Data Link Control layers. The Physical Layer is concerned with the transmission of unstructured bit streams over the physical transmission medium. It deals with the electrical, optical and functional characteristics for access to the physical medium. The DLC layer provides a reliable information transfer mechanism across the physical layer, particularly the physical link. Its primary responsibility is to provide error and flow control for the physical link, most of which is contained in the lowest sub-layer of the DLC. This is called the Media Access Control (MAC) sub-layer. The relationship of the MAC sub-layer with respect to the ISO Model DLC layer is depicted in figure 23.

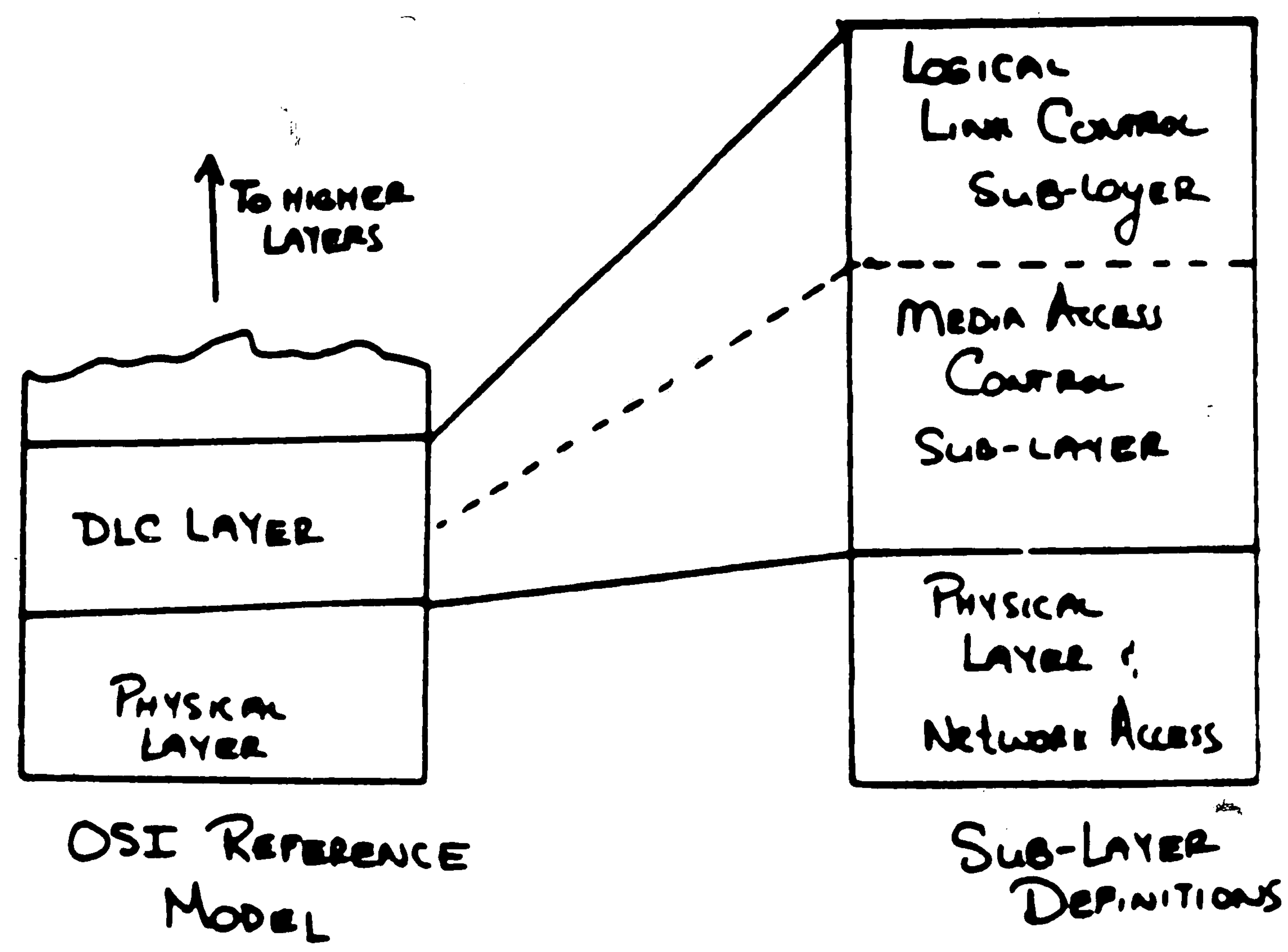

Figure 23. Physical Layer and MAC sub-layer Definitions

Figure 23 shows the correspondence between the bottom two layers of the ISO Reference model and the sub-layer definitions of the 802 family of LAN protocols. It is important to point out that physical link LAN functions are performed by the functions contained in the Physical Layer and MAC sub-layer only. They are not a part of the LLC sub-layer.

The IEEE 802.3 LAN protocol is currently implemented on the Mohler network with future plans to implement an 802.4 LAN protocol. The 802.3 protocol describes a collision detection and access (CSMA/CD) scheme for multiple node stations to communicate over LAN's transmission medium. The 802.4 LAN protocol describes an arrangement where node station access to the transmission medium is controlled by the acquisition of a *token*. The token permits a node station to access the bus, where only one node station at a time may possess the token. Both LAN protocols are explained thoroughly with an analysis of their ISO Model equivalent layers — the Physical layer and MAC sub-layer of the DLC. The following two sections provide details on the LAN protocols. The first section describes the operation of the 802.3 CSMA/CD LAN protocol, while the second section describes the 802.4 token passing bus protocol.

2.2.1 CSMA/CD (IEEE 802.3 Specification)

Architecturally, the 802.3 LAN protocol is divided into three layers — the Logical Link Control Layer, the Media Access Control Layer, and the Physical Layer. This is illustrated in figure 24.

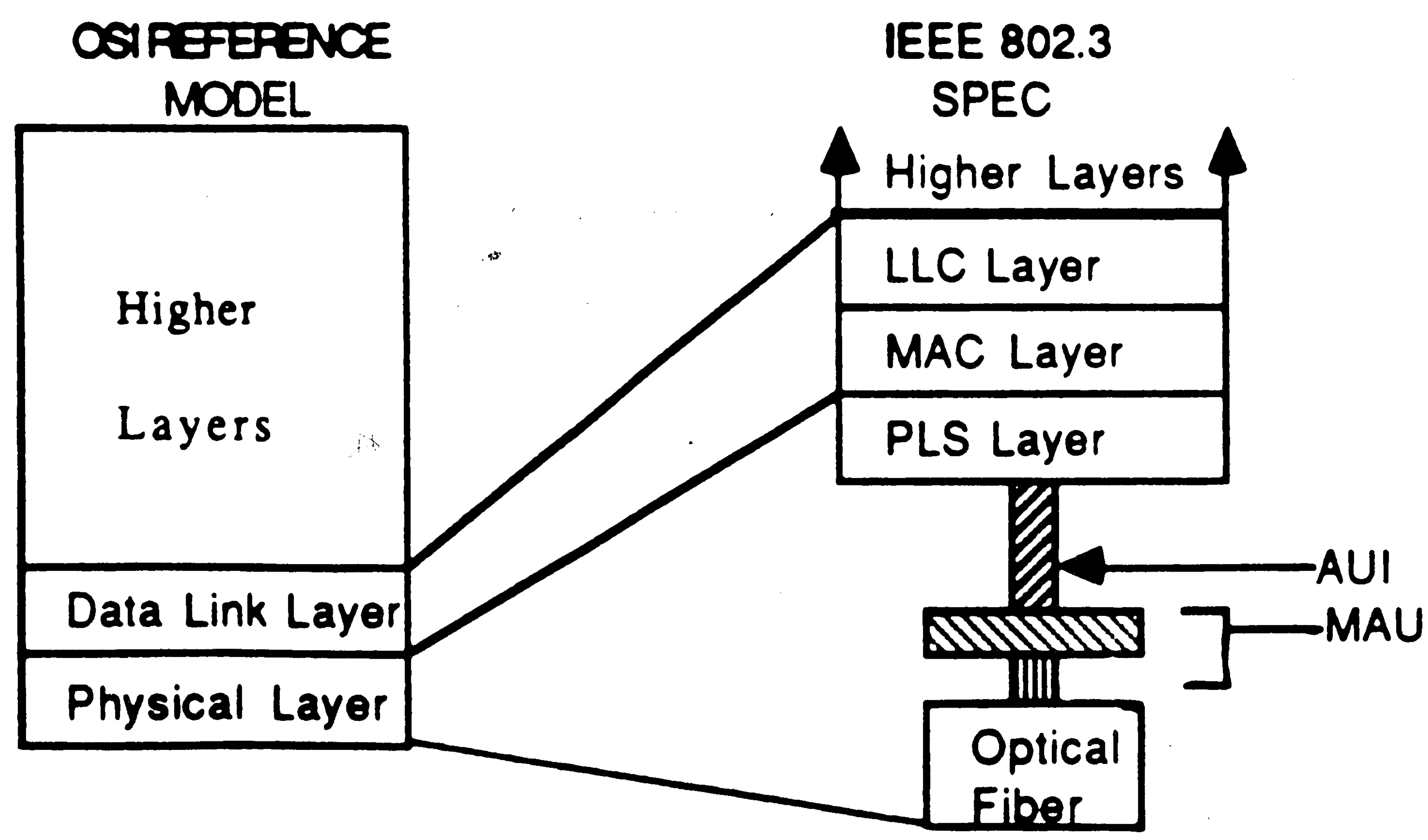

Figure 24. IEEE 802.3 Standard Relationship to ISO Model

The Physical Layer encompasses the hardware necessary to access the transmission medium.

It is composed of the Physical Signaling layer, the Attachment Unit Interface (AUI), the Medium Attachment Unit (MAU) and the transmission media. The LLC layer is responsible for setting up virtual data channels for the node station. This is important but will not be discussed further in this paper. The lower layers are responsible for making the physical connection to the transmission medium. They include the MAC and Physical Layers. These two layers correspond to the lower portion of the Data Link Control layer and entire Physical layer referenced in the ISO model in figures 22 and 24.

The two architectural divisions offer clarity and flexibility to allow data transmission over the optical fiber bus and other various physical media, including twisted-pair cable, coaxial cable, thick-net and thin-net drop cable. This is a very important consideration for providing connection to node stations which require physical access to media other than optical fiber. The Mohler 802.3 network permits connection to all types of these physical media with the primary emphasis placed on the optical fiber bus. This is important, because the Mohler building houses many small CSMA/CS LANs using different transmission media. The main campus network is also a CSMA/CD network. This will allow the 802.3 Mohler network to make connection to the campus network and most other small sub-networks in the building[15] [16]. The next two sections provide details on the 802.3 protocol operation. The first section outlines the responsibilities and functions of the protocol with respect to the node stations. The second section provides details on the operation of the physical layer with a description of its role in providing connection to the transmission media.

2.2.1.1 Protocol Synopsis

The 802.3 protocol specification allows many users to share network resources (file servers, printers, etc.) and connect to other network stations (electronic mail, file transfers, internetwork communication support, etc). The 802.3 specification refers to the method where two of more node stations can share a common transmission bus. In order for a node station to transmit on the transmission medium it waits for a quiet period. The station then starts a transmission and listens for its own signal on the medium. If the node station senses another station's signal, it sends out a jamming signal to signify that a collision has taken place. Each station involved with the collision sends out a brief jamming signal to assure that all stations know there has been a collision. After the jamming signal, each station waits a random amount of time. The stations are then free to transmit again using the 802.3 access method, hence the name Carrier Sense Multiple Access with Collision Detection (CSMA/CD), as it is sometimes called[2].

2.2.1.2 Physical Link Connection

The physical layer for the IEEE 802.3 LAN protocol is divided into three distinct regions — the Physical Signaling (PLS) layer, Attachment Unit Interface (AUI) region and the Medium Attachment Unit (MAU) region. This is depicted in figure 24. The PLS describes the portion of the physical layer contained within the DTE that provides functional coupling between the MAU and Data Link Layer. It is responsible for managing the collision detection mechanism and coordinating raw data flow in and out of the transmission medium. The transmission medium access port is composed of the MAU and AUI. The MAU defines the primary access to the physical link for this LAN protocol. The MAU supports a system configuration using CSMA access mechanisms defined for baseband signaling on the bus. The AUI consists of the cables, connectors and transmission circuitry used to interconnect the PLS and MAU. It is comprised of circuitry necessary to couple a node station's message path to/from the optical fiber transmission medium.

The physical layer, comprised of the PLS, AUI and MAU sub-layers operating as a unit, provide the following functions for coupling communication signals to the transmission medium:

- **Transmit Function**— The physical layer provides the ability to transmit serial data streams from the local node station to one or more remote node stations on the same transmission medium.
- **Receive Function**— The physical layer provides the ability to receive serial data streams over the transmission medium.
- **Collision Presence Function**— The physical layer provides the ability to detect the presence of two or more node stations' concurrent transmissions.
- **Monitor Function**— The physical layer provides the ability to inhibit normal transmit functions while the receive and collision presence functions remain active.
- **Jabber Function**— The physical layer provides the ability to interrupt the transmit function and inhibit long output data streams. (This is equivalent to a transmit override function.)

Figure 29 shows the third floor Mohler subnetwork connected to the entire Mohler LAN. The subnetwork uses the IEEE 802.3 LAN protocol and is implemented with a Codenal 4300 CSMA/CD multi-media interconnect repeater serving as the main floor node. The node stations are connected to the LAN with various transceivers. IBM PC equipment communicates with the LAN with Codenal 3C501 and 3030B transceivers. Sun workstations on the floor are connected to the LAN with a coaxial transceiver card. The card is a 4350 transceiver and is located in the interconnect repeater box. This equipment operates at 10M baud at $820nm$[17].

2.2.2 Token Bus (IEEE 802.4 Specification)

Architecturally, the 802.4 LAN protocol is divided into three layers — the Logical Link Control Layer, the Media Acess Control Layer, and the Physical Layer. This is illustrated in figure 25.

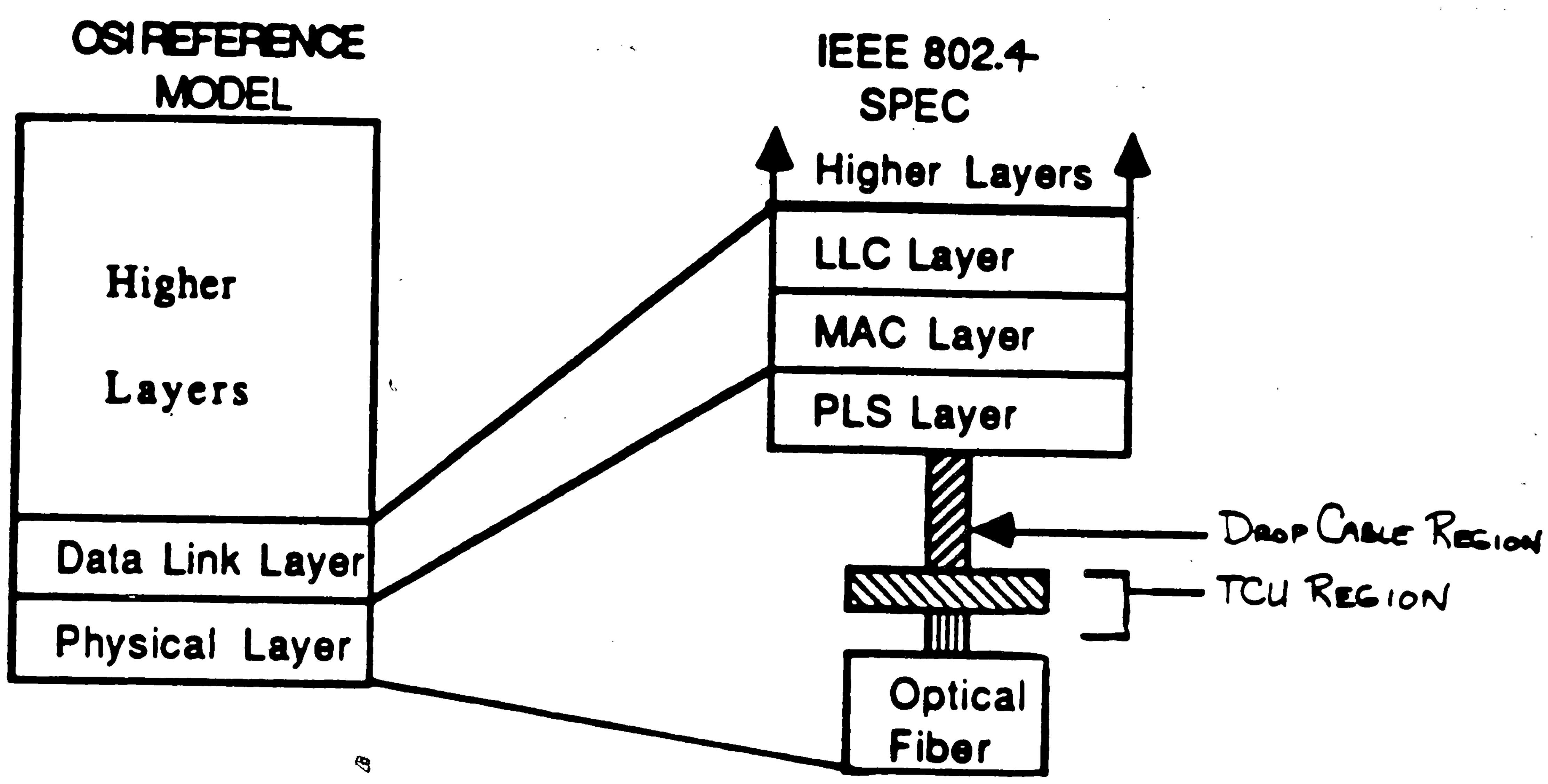

Figure 25. IEEE 802.4 Standard Relationship to ISO Model

The Physical Layer encompasses the hardware necessary to access the transmission medium. It is composed of the Physical Signaling layer, the drop cable region, the Trunk Coupling Unit (TCU) and the transmission media. The LLC layer is responsible for setting up virtual data channels for the node station. This is important but will not be discussed further in this paper. The lower layers are responsible for making the physical connection to the transmission medium. They include the MAC and Physical Layers. These two layers correspond to the lower portion of the Data Link Control layer and entire Physical layer referenced in the ISO model in figures 22 and 25[2][16]. The two layers in the 802.4 LAN protocol are responsible for controlling sequential node station access to the shared bus. Node stations are set up in a *logically circular fashion*, sometimes called a **logical token ring**. The "ring" consists a series of node stations connected to a shared bus. Node station access to the bus is controlled by passing a token from one node station to the next in the "ring" sequence. Only one node station at a time may possess a token and have control of the transmission medium. The 802.4 LAN protocol is defined in layers that interact with well defined interfaces as shown in figure 26. The Physical layer consists of circuitry needed to signal and gain control of the transmission medium. The interface to the MAC layer provides signals for framing, token acceptance, data polling, and facilities for passing transmit and receive bit streams to the bottom layer. The Media Access Control layer provides "typical MAC layer functions" for token control and general "ring" maintenance. Its functions include the following:

- Node station failure recovery
- Valid Token Recognition
- Node address recognition
- Ring member addition/deletion
- Distributed initialization of the LAN

A functional overview of the 802.4 LAN protocol is presented in following two sections. The first section gives a synopsis of the protocol functions with respect to the LAN node stations. The second section provides details of the physical layer, with a description of the hardware functions necessary to access the transmission medium.

2.2.2.1 Protocol Synopsis

The IEEE 802.4 LAN protocol allows many users to share the network bus and its resources.

The protocol refers to a method where node stations are permitted access to the transmission medium by a control packet known as a token. When a station receives a token, it is granted complete control of the media for a specified period of time. This is an important capability for large, uninterrupted, data transfers between node stations. When a node station completes transmission, it passes the token to the next station in sequence on a *logical ring*. This node station now has the right to transmit over the transmission medium[2].

Node stations that do not have control of the token can still respond to requests from the station possessing control, though, they cannot initiate requests. Overall, steady state operation consists of a data transfer and a token transfer phase, with one node station providing various "ring" maintenance functions[3]. They include:

- *Logical Ring* initialization
- Lost token recovery
- Node station addition/deletion from the *Logical Ring*
- General housekeeping for *Logical Ring.*

2.2.2.2 Physical Link Connection

The physical link connection for the IEEE 802.4 protocol specification is divided into three regions—the Physical Signaling (PLS) layer, Drop Cable region and the Trunk Coupling Unit (TCU) region. This is illustrated in figure 26. The PLS layer consists of transceiver circuitry

3. All the nodes stations on the *logical ring* are capable of providing "ring" maintenance function. Only one station actually provides the function. If that station fails, another designated station takes its place, and so forth, in a predesignated pecking order.

used to setup and control a duplex data stream from higher MAC sub-layer functions. The Drop Cable region consists of a short multi-conductor cable that connects the PLS and TCU. The TCU consists of a bidirectional matching tap that performs necessary transmission functions over the bus. The TCU converts signal information carried along the drop cable from the PLS, to the proper baseband transmission format[16]. Here, the TCU would covert duplex electrical signal information to an equivalent 1300nm fiber optic signal, as specified in a future update for the Mohler LAN.

The physical layer, consisting of the PLS, Drop Cable region and TCU, provide the following network communication functions:

- **Symbol Transmission and Reception Functions**—These functions are used to control the transceiver directly. They are used to modulate signal information in a multi-level AM/PSK format. In the case where no signal information is available, *pad_idle* symbols are send over the transmission medium to designate an idle transmission state.

- **Jabber Inhibit Function** — This function is used to protect the LAN from most faults in a node station. When a node station experiences repeated difficulty with a transmission, it senses the problems and instructs the transmitter to disable itself. The jabber inhibit function is necessary to provide control over node station failures. This function isolates the node station, at least temporarily, from the transmission media and the remaining node stations on the LAN, in the event of a node station failure. The Mohler LAN bus is shared by every node station. Every station receives the signals from every other station. It is necessary to ensure that all of the stations are operating correctly. Any one malfunctioning station is capable of corrupting the entire LAN.

3. Network Maintainability

Network maintainability is often the most overlooked issue when designing or deploying a Local Area Network (LAN). Once a network is designed, provisions have to be made on how to spot failures in the physical link, and how to correct them. Another issue often overlooked in maintaining a Local Area Network is how to introduce change. This usually, but not always, involves issues with the physical link configuration and its topology. Any changes to the physical network should adhere to the following design objectives:

- The design should facilitate simple LAN maintenance
- The design should provide for reliable LAN operation
- It should allow for future LAN expansion and growth

A 802.3 CSMA/CD network is deployed in the Mohler building with future plans to implement the 802.4 LAN protocol. Maintainability issues center around the hardware used to implement the LAN protocols. The bus is composed of $62.5/125\mu m$ graded index multimode optical fiber, insertion connectors, optical star couplers and an array of active repeaters and transceivers. These components may be found in figure 29 in appendix A. LAN maintainence provides support for this equipment. Maintenance includes measures to ensure proper operation of the equipment and provisions for network expansion. The LAN topology is expandable and reconfigurable. The following two section discuss the issues necessary to support LAN operations and promote change. The first section outlines various failure mechanisms in the Mohler LAN and their consequences on network operations. The last section discusses LAN modifications. This section describes situations which necessitate changes in the LAN architecture. They include LAN protocol changes, topology changes and data throughput changes.

3.1 Network and Sub-network Isolation

By choosing a bus topology for the physical link, failures are usually limited to individual node stations or local sub-networks within the Mohler LAN. The subnetwork layout is shown in figure 29 in appendix A. Recovery from subnetwork or node station failures increases the reliability of a Local Area Network design by allowing the physical link to remain functional if failures occur. Failure events are rare, but are kept track of by protocol layers higher than the physical layer, thereby passing responsibility of the event to the node station, not the network physical link. This is important in reducing the downtime of the network backbone.

As long as the physical link remains intact, node station failures will not disable the Mohler network. On the other hand, failures in the physical link such as:

- Optical Fiber breakage
- Star-coupler Failures
- Improper Optical Fiber terminations
- Active Coupler/Repeater Failures

cause the entire network, or at the very least, a sub-network to go down. Failures of this type render the transmission medium impassable. The Mohler 802.3 LAN accounts for failures of this type by disabling subnetwork segments, effectively removing them from the network. This is an implemented feature of the Codenal 4311 interconnect CSMA/CD repeater that is used as a main floor node. The interconnect unit partitions subnetwork segments from the remainder of the LAN in the event of a transmission medium failure.

The following two sections outline these type network failures and provide measures on how to rectify their occurrence. The first section describes node station failures and their effect on the LAN. The second section describes physical link failures and their effect on the LAN transmission bus.

3.1.1 Node Station Failure

Failure events in the physical network are characterized by their effect on the entire LAN. Node station failures tend to isolate individual users,and their resources, from the remainder of the network and are characterized by having virtual data flow disrupted at the node station transceiver. This is depicted in figure 26, showing a particular sub-network in the Mohler LAN.

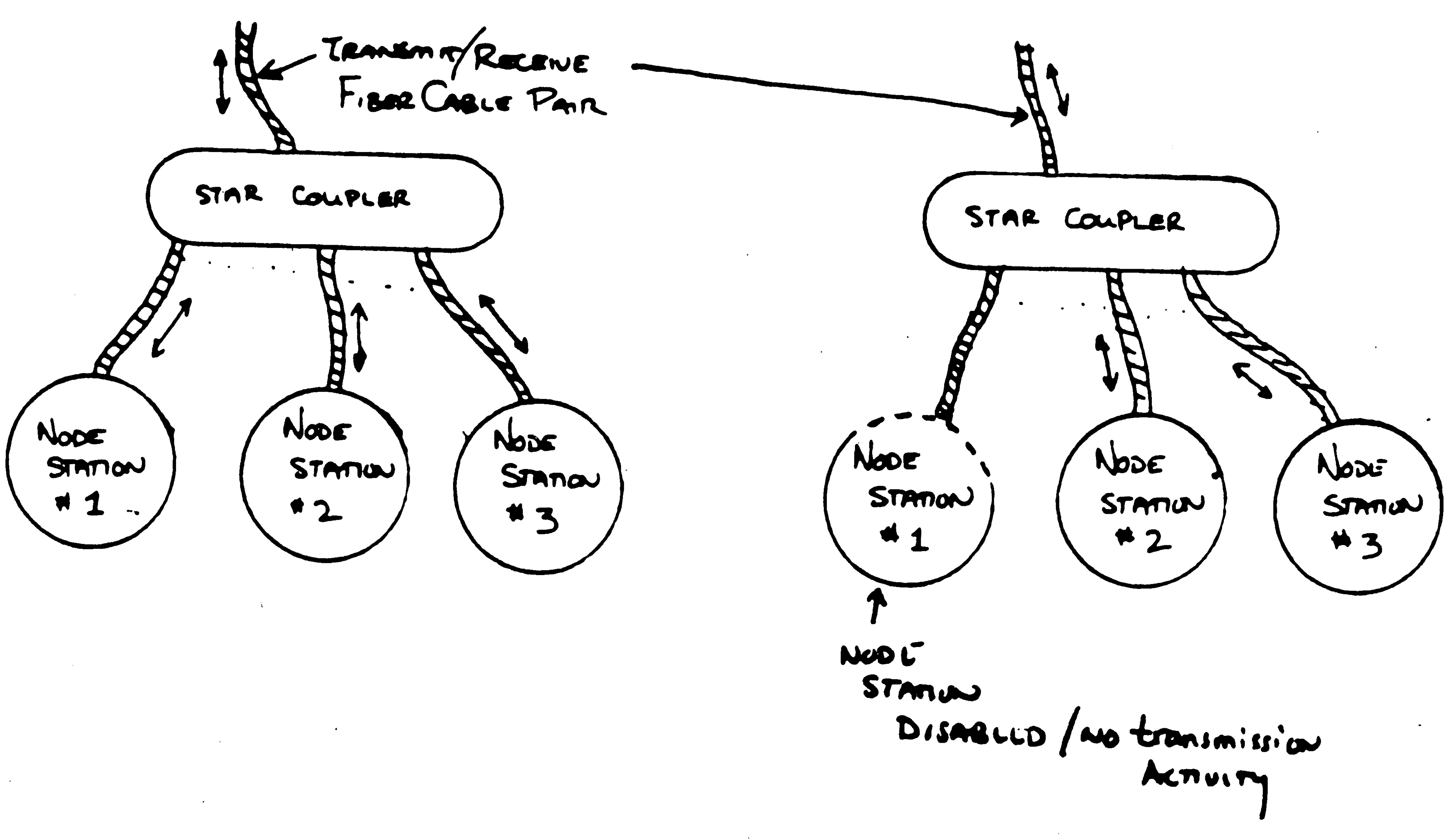

Figure 26. Node Station Failure in Particular Section of the Mohler LAN

This figure illustrates the effect of a node station failure in a subnetwork. The subnetwork on the left shows nodes stations 1 through 3 functioning properly. All stations are capable of accessing the transmission medium. Node station 1 experiences difficulty with its transmitter and disables it. The figure on the right shows the effect of node station 1 being removed from the subnetwork. Node stations 2 and 3 are still functional, while node station 1 is blocked from receiving or transmitting data on the transmission medium. This feature is incorporated in the higher level protocol layers of the node station, particularly the MAC sub-layer. The figure on the left depicts three node stations communicating at $820nm$ on the optical fiber bus. Note the tree structure of the bus. The figure on the right illustrates an occurrence of a typical node station failure. The node station disables its transceiver, and the other two stations are free to communicate, thus preserving the communication abilities for the remainder of the LAN.

It is important to realize that node stations failures are rare, but their occurrences are usually marked by the following events:

- Transceiver Malfunctions
- Node Station Malfunctions (Host computer or terminal malfunction)
- Node Station Power Failures

3.1.2 Physical Link Failure

Physical Link Failures, on the other hand, occur less frequently than node station failures. Physical link failures are characterized by a restriction of optical energy somewhere in the bus or transceiver. This type of failure is more difficult to isolate and correct with an operational LAN. Failures are usually detected by discovering a series of node stations on the bus that experience difficulty in communicating with the remainder of the network.

Physical link failures usually affect more than one node station at a time because of their effect on the LAN bus. Figure 27 shows an example of a physical link failure.

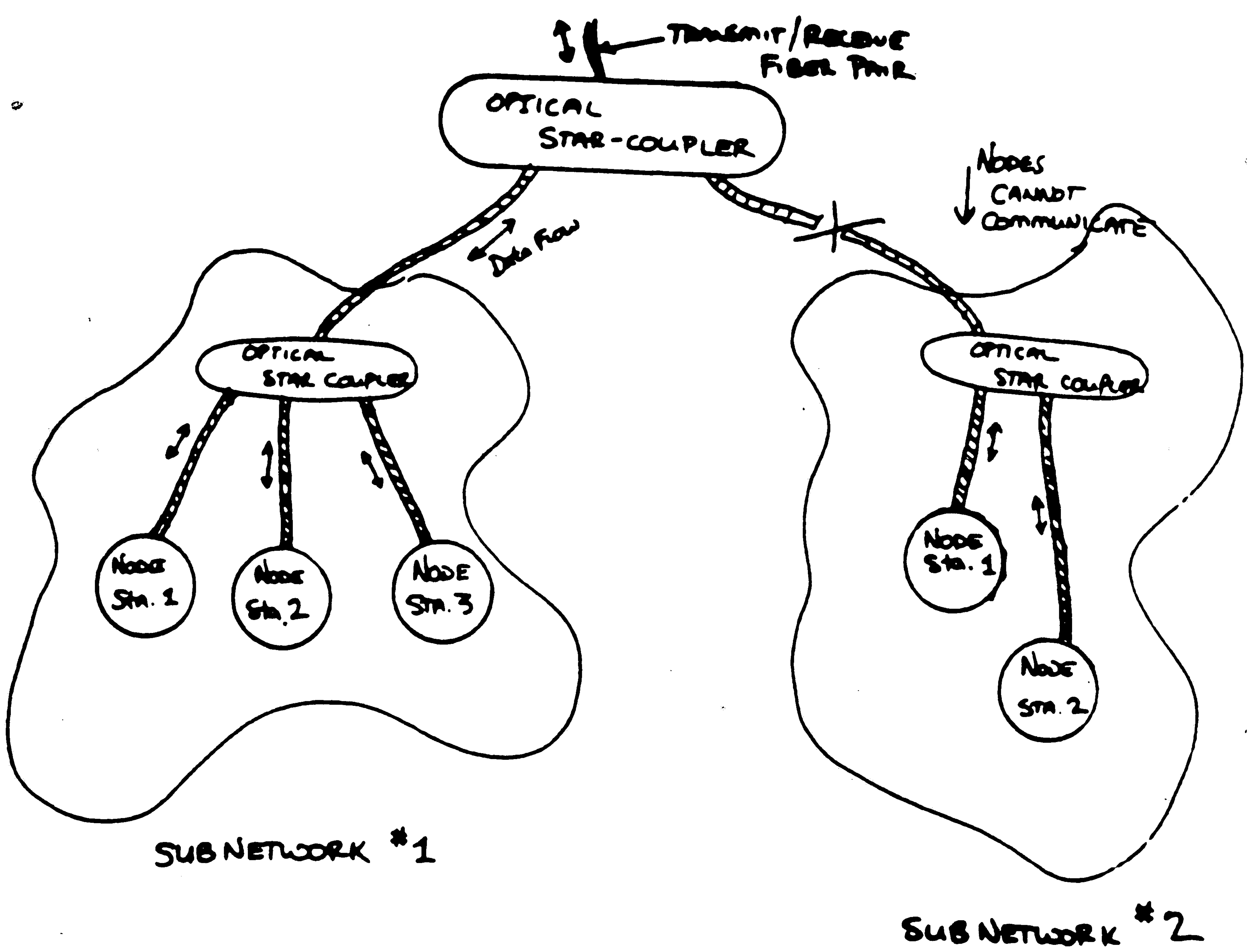

Figure 27. Physical Link Failure on Mohler LAN

The optical fiber is broken between the main floor node and the subnetwork 2 optical couplers. The bus at this point is impassable. The failure tends to isolate an entire section of the bus from the remainder of the LAN. The other portion of the network remains functional. In this case, Subnetwork #1 remains connected to the LAN, while subnetwork #2 is isolated. Node stations within the subnetwork are still able to communicate with each other, but not with node stations in other subnetworks.

Common physical link failures are listed below. Please refer to figure 29 in appendix A for the location of PFCs and transceivers in the Mohler LAN.

PFC Failures:

- *Optical Fiber Breakage* — Fiber breakage causes every node station on that section of the buss to be isolated from the remainder of the LAN. This type of failure is shown in figure 28 and is reviewed in the previous section.

- *Star Coupler Failures* — Star Coupler failures cause an entire *Network Division* to become isolated from the LAN. This type of failure isolates a subnetwork from the remainder of the LAN. Its effects are also shown in figure 28. If the failure occurs with a main floor node coupler, the entire floor is isolated from the LAN.

- *Optical Connector Failures* — Connector failures are usually caused by misalignment or stress induced fractures in the connector itself. Failures usually result in high transmission error rates on the LAN, or no data throughput at all, for any node station on that particular section of the bus. They have the same effect as a break in an optical fiber. This type of failure is discussed in the preceding paragraphs. Connector failures introduce high attenuation losses into a particular branch of the transmission bus. This lowers the link loss margin available from the LAN transceivers. High losses cause transceivers to receive optical information at or below its minimum detectable signal level, subsequently causing data errors.

Transceiver Failure:

In general, transceiver failures affect only a particular node station, not the entire LAN. They are not as severe as PFC failures, which can wipe out entire sections of the physical link.

- *Transmitter Failures* — Transmitter failures cause a particular node station to not be able to send data. They usually result in a node station being disabled and logically removed from the LAN, at least until the failure is corrected.

- *Receiver Failures* — Receiver failures cause a particular node station to not be able to receive data from the LAN. These failures are more difficult to detect, especially, if node stations are receiving a broadcast transmission.

3.2 LAN Modifications

As data communication needs for the Mohler building change and more efficient network resources become available, there will be a need to modify the LAN accordingly. The choice of a bus architecture and optical fiber transmission medium which has been made provides the vehicle to achieve these changes with little difficulty. Consideration must be given to transceiver wavelength operation, data throughput requirements, and changes to the physical link topology, in evaluating an implementation scheme that preserves the original design objectives.

With time, there might be a need to:

— Implement additional protocol specifications (IEEE 802.5, etc) on the fiber transmission medium.

— **Reassign protocol transceiver wavelengths.**

— Increase the effective data throughput of a protocol specification.

— Add additional taps on the fiber transmission medium

— Increase lengths and/or change locations of optical fiber taps on the transmission medium.

The following sections outline the considerations necessary to execute such changes.

3.2.1 Transmission Wavelength Considerations

The physical link used in the Mohler LAN is characterized by having an extremely large bandwidth ($>$ 300 Mhz). The PFCs used in the LAN architecture exhibit reasonable loss and dispersion characteristics for a wide range of transmission wavelengths. This has been experimentally proven in the laboratory for wavelengths from 700 to 1550nm. Measured optical star coupler and multimode fiber losses may be found in appendix D of this documents. The measurements were taken at 830 and 1300nm.

Transceiver wavelengths may be changed or added to the LAN. The only restriction is that multiple wavelength transmission may require bandpass filters for each tap on the optical bus. This is to ensure proper data reception at a particular transceiver; it also ensures that a transceiver will not confuse signal information traveling at different wavelengths, especially, if they are closely related. Figure 29 shows a LAN using Wavelength Division Multiplexing.

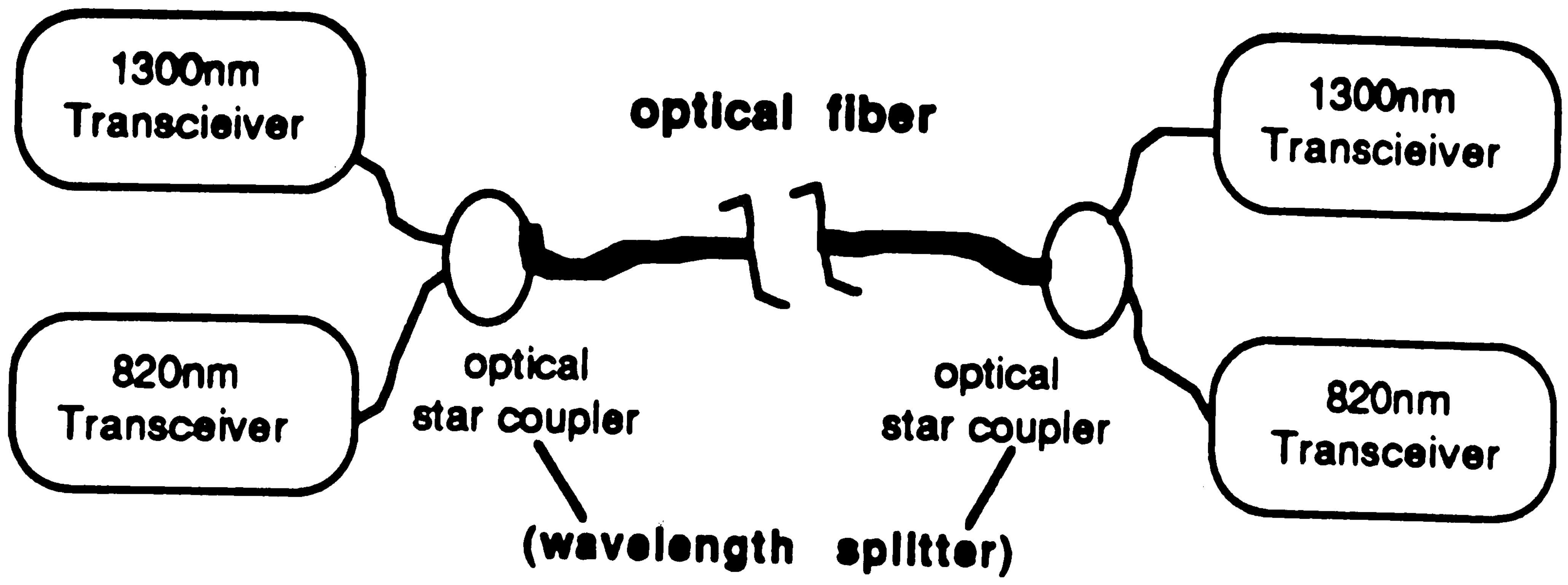

Figure 28. WDM Procedures for 820 and 1300nm Operations

The figure shows two different types of LAN transceivers. One communicates at 820*nm* while the other communicates at 1300*nm*. The optical star coupler on the left combines the signals from each transmitter and send the both over the optical fiber. The star coupler at the other end of the fiber distributes the superimposed signal information to both transceivers on the right. Each transceiver's receiver must filter out the unwanted wavelengths with optical bandpass filters.

In theory, it is possible to superimposed many different wavelengths on a LAN transmission medium. Fiber lengths in the Mohler LAN are small (see data in appendix D.1); attenuation losses due to the fiber are therefore low for a wide range of frequences (see figure 8 in section 2.1). LAN transceivers are currently available for wavelengths in the range 680 to 1600*nm*, with the most common being 820*nm*, 1300*nm* and 1550*nm*.

3.2.2 Data Throughput Considerations

The Mohler optical fiber transmission medium has the capability of supporting very large data traffic. This places a maximum achievable data throughput on the LAN in the hundreds of megabaud. Currently, the transceivers deployed for the 802.3 Mohler network operate at 10M baud. Increased data throughput requirements for the Mohler LAN can be met by either updating the transceivers used at for node stations or by using WDM procedures, where many transceivers can be used in parallel. There are a large number of different transceiver wavelengths available that can be used to do this.

3.2.3 Physical Topology Considerations

LAN Topology changes are sometimes necessary either because node station locations have changed or because there is a requirement for additional LAN connections in the building. The Mohler LAN is relatively small. Maximum optical fiber lengths encountered anywhere in the building are less than 100 meters. Fiber attenuation is never a great concern for Mohler LAN because of this. Losses at $820nm$ are less than $3.5dB/km$.

The star couplers used in the LAN are only 50 percent occupied. On the average only 9 ports are being used out of a possible 16. This leaves plenty of room for addional network connection at the subnetwork level (see coupler port assignments in appendix B.1.2). Overall, the only requiment for reconfiguring coupler locations and/or adding couplers to the LAN is the total link loss budget must be preserved. The total link loss between any two transceivers in the LAN must be less than the transceiver power budget. Details of the power budget are discussed in section 2.1.5.

4. Conclusion

I have described here a prototype LAN architecture which is based on a hybrid optical star bus composed of active and passive components. The bus is configured to operate at any desired wavelength. Initially, the Mohler LAN supports a CSMA/CD-based protocol operating at 830*nm*, with future plans to support a token passing bus protocol operating at 1300*nm*. This will be implemented using Wavelength Division Multiplexing and is described in section 3 of this document. The Mohler LAN is able to support heavy traffic loads and provide immediate access to local and remote network resources. It operates at a 10M baud data rate, with full Internet and file transfer facilities available from any node station in the building.

The Optical star bus is very efficient and reliable. It is composed of biconically tapered star couplers, 62.5/125μm multimode optical fiber and is connected with ST and FSD insertion connectors. The hybrid architecture is easily expanded for future needs[18]. With proper transceivers, the optical star bus is capable of supporting data rates as high as 360M baud at 820*nm* and high rates at longer wavelengths (see table 1).

A. LAN Physical Layout

The Mohler LAN is distributed among floors in the Mohler building. Figure 30 shows a schematic of the LAN with its node locations. The figure shows the network and subnetwork boundaries assigned to the LAN. Specific detail on equipment inventories and locations may be found in the following appendices:

Equipment	Location in Document
Optical Couplers	Appendix B
Optical Fiber Runs	Appendix D.1
Transceivers	Appendix B.2
Miscellaneous	Appendix B.3

Blueprints were acquired from the Mohler Building Renovation project and modified accordingly to show the locations of fibers, fiber outlets and fiber optics equipment. These drawings were transferred to a CAD drawing system. Each of the four CAD drawings covers a specific floor in the Mohler Building. The first CAD drawing shows the layout on the first floor. The second drawing shows the second floor and so forth for the third and fourth drawings.

Details for the Mohler LAN Layout are separated into two sections. The first section gives reference data for the four CAD drawings. The second section tabulates, on a floor-by-floor basis, all network and subnetwork boundaries defined for this LAN project.

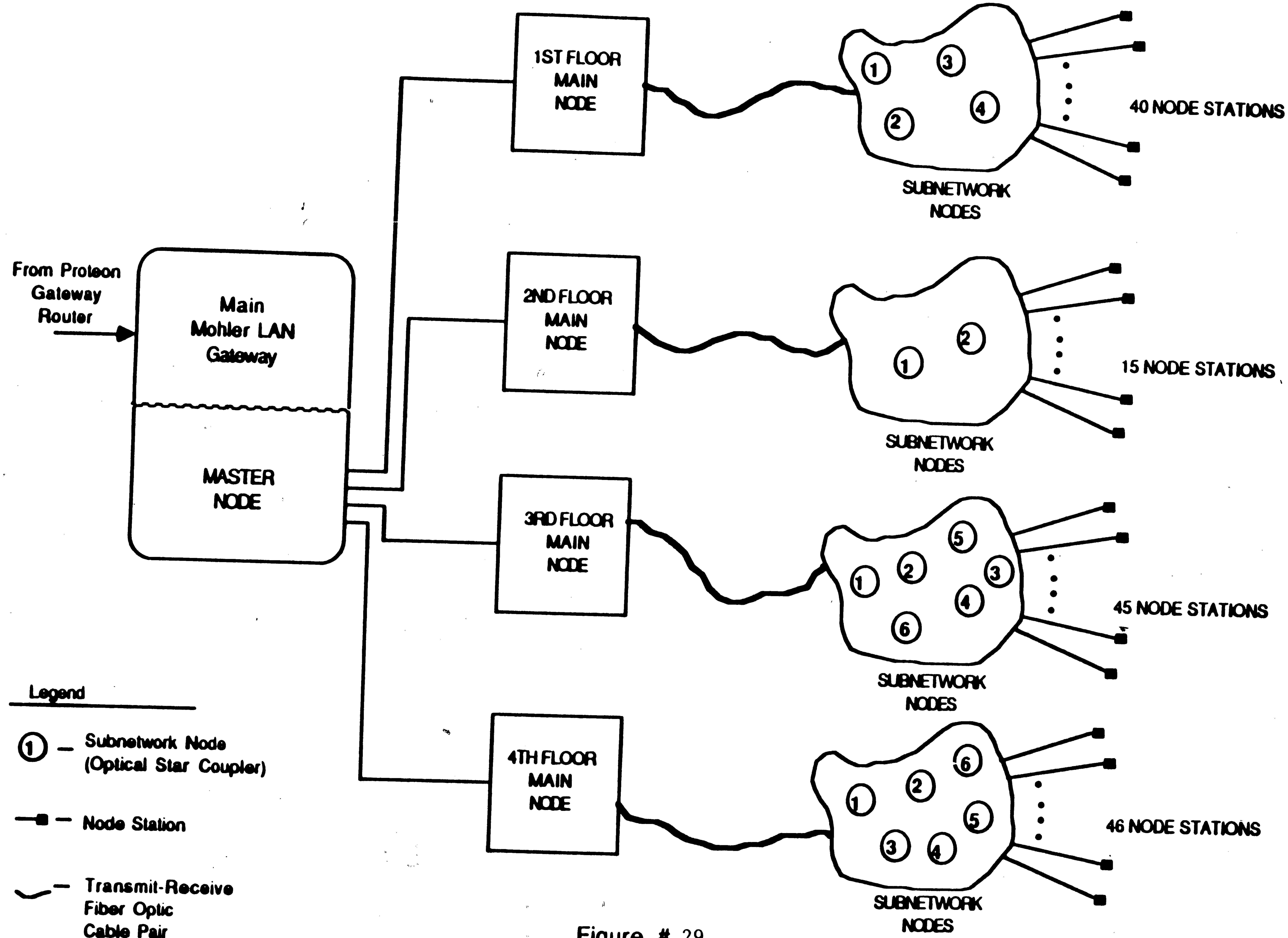

Figure # 29

MOHLER FIBER OPTIC LAN

A.1 Mohler Building CAD Drawings

The following table shows the CAD drawing reference information for each of the four floor in the Mohler Building:

Mohler CAD Drawings		
Floor #	Library Name	Data Location
1	Mohler_Fiber_Optic_LAN.1	*CADM System under library USERB*
2	Mohler_Fiber_Optic_LAN.2	*CADM System under library USERB*
3	Mohler_Fiber_Optic_LAN.3	*CADM System under library USERB*
4	Mohler_Fiber_Optic_LAN.4	*CADM System under library USERB*

Table 3. CAD Drawing Reference Information

Note that all plots are to be printed on the Benson Electro-static plotter with a frame of $19.5X32$ inches. A bound release of the latest CAD drawings may be found in Professor Richard Denton's office in Packard Laboratory at Lehigh University.

A.2 Sub-network Grouping Scheme

The following table outlines the sub-network groups defined for the Mohler Network. Information is given with respect to subnetwork ID's, room numbers, and cable number groupings. The *Floor-Network Division* refers to a large network boundary on a specific floor. For example, the Floor-Network Divisions, 1-A and 1-B, represent two network boundaries whose fiber optics equipment connections are located on the first floor. The *Subnet Group* refers to a specific star-coupler within a Floor-Subnet region. For example, Floor-Subnet region 1-A might use four optical star couplers to connect its nodes to the equipment cabinet. Subsequently, region 1-A would have four separate Subnet Groups to describe this. *Tap Room Number* refers to the room where the node station (FSD wall outlet) is located. The *Cable ID* refers to the cable identification number given to a specific optical fiber. For example, cable ID #1-23 refers to cable 23 on floor 1. The same scheme is used for the remaining three floors.

The first floor has one network division with 40 node stations connected by 4 Subnet Groups. The second floor also has one network division with 15 node stations connected by 2 subnet groups. Both the first and second floor networks are Operated by transceiver equipment located in room 146 on the first floor. The third floor has two major network divisions with a total of 45 node stations. Each division has 3 subnet groups associated with it; both divisions are operated by transceiver equipment located in room 337 on the third floor. The fourth floor has only one network division. This division has 46 node stations connected by 6 subnet groups. These groups are operated by transceiver equipment located in room 437.

Floor-Network Division	Subnet Group	Cable ID	Tap Room Number
1-A	1.1 (Star #1187054)	1-1	171
1-A	1.1	1-2	171
1-A	1.1	1-3	171
1-A	1.1	1-4	171
1-A	1.1	1-5	171
1-A	1.1	1-6	171
1-A	1.1	1-7	171
1-A	1.1	1-8	171
1-A	1.1	1-9	171
1-A	1.1	1-10	171
1-A	1.2 (Star #1187078)	1-11	171
1-A	1.2	1-12	171
1-A	1.2	1-13	171A
1-A	1.2	1-14	171A
1-A	1.2	1-15	171A
1-A	1.2	1-16	171
1-A	1.2	1-17	110
1-A	1.2	1-18	120
1-A	1.2	1-19	110
1-A	1.2	1-20	112
1-A	1.3 (Star #1187072)	1-21	146
1-A	1.3	1-22	112
1-A	1.3	1-23	142
1-A	1.3	1-24	142
1-A	1.3	1-25	110
1-A	1.3	1-26	121
1-A	1.3	1-27	121
1-A	1.3	1-28	121
1-A	1.3	1-29	121
1-A	1.3	1-30	121A
1-A	1.4 (Star #1187074)	1-31	121
1-A	1.4	1-32	121
1-A	1.4	1-33	121
1-A	1.4	1-34	121
1-A	1.4	1-35	121

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Floor-Network Division	Subnet Group	Cable ID	Tap Room Number
1-A	1.4	1-36	121
1-A	1.4	1-37	121
1-A	1.4	1-38	121
1-A	1.4	1-39	121A
1-A	1.4	1-40	121A

Table 4. Network Group Scheme (First Floor)

Floor-Network Division	Subnet Group	Cable ID	Tap Room Number
1-B	2.1 (Star #1287185)	2-1	210
1-B	2.1	2-2	210
1-B	2.1	2-3	210
1-B	2.1	2-4	210
1-B	2.1	2-5	210
1-B	2.1	2-6	210
1-B	2.1	2-7	210
1-B	2.1	2-8	210
1-B	2.2 (Star #1287191)	2-9	206
1-B	2.2	2-10	205
1-B	2.2	2-11	204
1-B	2.2	2-12	200
1-B	2.2	2-13	201
1-B	2.2	2-14	203
1-B	2.2	2-15	203

Table 5. Network Grouping Scheme (Second Floor)

Floor-Network Division	Subnet Group	Cable ID	Tap Room Number
3-A	3.1 (Star #1187081)	3-1	389
3-A	3.1	3-2	380
3-A	3.1	3-3	388
3-A	3.1	3-4	380
3-A	3.1	3-5	381
3-A	3.1	3-6	385
3-A	3.1	3-7	387
3-A	3.1	3-8	375
3-A	3.2 (Star #1187075)	3-9	301
3-A	3.2	3-10	301
3-A	3.2	3-11	304
3-A	3.2	3-12	304
3-A	3.2	3-13	325
3-A	3.2	3-14	323
3-A	3.2	3-15	322
3-A	3.2	3-16	321
3-A	3.3 (Star #1187076)	3-17	327
3-A	3.3	3-18	304
3-A	3.3	3-19	329
3-A	3.3	3-20	320
3-A	3.3	3-21	320
3-A	3.3	3-22	320
3-A	3.3	3-23	358
3-A	3.3	3-24	371
3-A	3.4 (Star #1288188)	3-25	371
3-A	3.4	3-26	371
3-A	3.4	3-27	356
3-A	3.4	3-28	356
3-A	3.4	3-29	356
3-A	3.4	3-30	358
3-A	3.4	3-31	362
3-A	3.4	3-32	362
3-A	3.5 (Star #0787138)	3-33	362
3-A	3.5	3-34	362
3-A	3.5	3-35	362

(continued on next page . . .)

Floor-Network Division	Subnet Group	Cable ID	Tap Room Number
3-A	3.5	3-36	362
3-A	3.5	3-37	355
3-A	3.5	3-38	355
3-A	3.5	3-39	355
3-A	3.5	3-40	358
3-A	3.6 (Star #1187055)	3-41	353
3-A	3.6	3-42	353
3-A	3.6	3-43	342
3-A	3.6	3-44	342
3-A	3.6	3-45	342

Table 6. Network Grouping Scheme (Third Floor)

Floor-Network Division	Subnet Group	Cable ID	Tap Room Number
4-A	4.1 (Star #0987002)	4-1	484
4-A	4.1	4-2	484
4-A	4.1	4-3	486
4-A	4.1	4-4	485
4-A	4.1	4-5	479
4-A	4.1	4-6	481
4-A	4.1	4-7	444A
4-A	4.1	4-8	478
4-A	4.2 (Star #1187079)	4-9	444A
4-A	4.2	4-10	401
4-A	4.2	4-11	421A
4-A	4.2	4-12	421
4-A	4.2	4-13	421
4-A	4.2	4-14	421
4-A	4.2	4-15	421C
4-A	4.2	4-16	429
4-A	4.3 (Star #1287186)	4-17	
4-A	4.3	4-18	477
4-A	4.3	4-19	475
4-A	4.3	4-20	475
4-A	4.3	4-21	476
4-A	4.3	4-22	473
4-A	4.3	4-23	471
4-A	4.3	4-24	472
4-A	4.4 (Star #1287189)	4-25	472
4-A	4.4	4-26	453
4-A	4.4	4-27	453
4-A	4.4	4-28	453
4-A	4.4	4-29	453
4-A	4.4	4-30	453A
4-A	4.4	4-31	453
4-A	4.4	4-32	453A
4-A	4.5 (Star #1187080)	4-33	444
4-A	4.5	4-34	444
4-A	4.5	4-35	444

(continued on next page . . .)

Floor-Network Division	Subnet Group	Cable ID	Tap Room Number
4-A	4.5	4-36	444
4-A	4.5	4-37	444
4-A	4.5	4-38	444
4-A	4.5	4-39	451
4-A	4.5	4-40	451
4-A	4.6 (Star #1287192)	4-41	451
4-A	4.6	4-42	451
4-A	4.6	4-43	451
4-A	4.6	4-44	451A
4-A	4.6	4-45	451A
4-A	4.6	4-46	451

Table 7. Network Grouping Scheme (Fourth Floor)

B. Optical Fiber Equipment Inventory

The following tables list the fiber optic equipment inventory used for the Mohler LAN project, on a floor-by-floor basis. When possible, pertinent interconnection information is included. The equipment inventory is broken into three main sub-sections. The first sub-section lists the optical couplers used in the Mohler LAN. The second sub-section lists the transceivers used in the LAN. The last subsection lists various miscellaneous fiber optic equipment used.

B.1 Optical Star-Couplers

B.1.1 Location Assignments

Serial Number	*Description*
#1187054	*AMP 16 X 16 Multimode Fiber Optic Coupler. Located in interconnection closet in room 142. It is used for Subnet 1.1*
#1187078	*Same, except used for Subnet 1.2*
#1187072	*Same, except used for Subnet 1.3*
#1187074	*Same, except used for Subnet 1.4*
#1287185	*Same, except used for Subnet 2.1*
#1287191	*Same, except used for Subnet 2.2*
#1187081	*AMP 16 X 16 Multimode Fiber Optic Coupler. Located in interconnection closet in room 337. It is used for Subnet 3.1*
#1187075	*Same, except used for Subnet 3.2*
#1187076	*Same, except used for Subnet 3.3*
#1288188	*Same, except used for Subnet 3.4*
#0787138	*Same, except used for Subnet 3.5*
#1187055	*Same, except used for Subnet 3.6*
#0987002	*AMP 16 X 16 Multimode Fiber Optic Coupler. Located in interconnection closet in room 437. It is used for Subnet 4.1*
#1187079	*Same, except used for Subnet 4.2*
#1287186	*Same, except used for Subnet 4.3*
#1287189	*Same, except used for Subnet 4.4*
#1187080	*Same, except used for Subnet 4.5*
#1287192	*Same, except used for Subnet 4.6*
#1287187	*AMP 16 X 16 Multimode Fiber Optic Coupler. Located in interconnection closet in room 337. It is used as the Master Building Star*

Table 8. Optical Coupler Locations

B.1.2 Interconnection Scheme

Subnet Group (Star ID#)	Coupler port pair	Cable ID	Subnet Group (Star ID#)	Coupler port pair	Cable ID
1.1 (Star #1187054)	#1	1-1	1.3 (Star #1187074)	#1	1-21
	#2	1-2		#2	1-22
	#3	1-3		#3	1-23
	#4	1-4		#4	1-24
	#5	1-5		#5	1-25
	#6	1-6		#6	1-26
	#7	1-7		#7	1-27
	#8	1-8		#8	1-28
	#9	1-9		#9	1-29
	#10	1-10		#10	1-30
1.2 (Star #1187054)	#1	1-11	1.4 (Star #1187074)	#1	1-31
	#2	1-12		#2	1-32
	#3	1-13		#3	1-33
	#4	1-14		#4	1-34
	#5	1-15		#5	1-35
	#6	1-16		#6	1-36
	#7	1-17		#7	1-37
	#8	1-18		#8	1-38
	#9	1-19		#9	1-39
	#10	1-20		#10	1-40

Table 9. Coupler Interconnect Scheme (First Floor)

Subnet Group (Star ID#)	Coupler port pair	Cable ID	Subnet Group (Star ID#)	Coupler port pair	Cable ID
2.1 (Star #1287185)	#1	2-1	2.2 (Star #1287191)	#1	2-9
	#2	2-2		#2	2-10
	#3	2-3		#3	2-11
	#4	2-4		#4	2-12
	#5	2-5		#5	2-13
	#6	2-6		#6	2-14
	#7	2-7		#7	2-15
	#8	2-8			

Table 10. Coupler Interconnect Scheme (Second Floor)

Subnet Group (Star ID#)	Coupler port pair	Cable ID	Subnet Group (Star ID#)	Coupler port pair	Cable ID
3.1 (Star #1187081)	#1	3-1	3.4 (Star #1288188)	#1	3-25
	#2	3-2		#2	3-26
	#3	3-3		#3	3-27
	#4	3-4		#4	3-28
	#5	3-5		#5	3-29
	#6	3-6		#6	3-30
	#7	3-7		#7	3-31
	#8	3-8		#8	3-32
3.2 (Star #1187075)	#1	3-9	3.5 (Star #0787138)	#1	3-33
	#2	3-10		#2	3-34
	#3	3-11		#3	3-35
	#4	3-12		#4	3-36
	#5	3-13		#5	3-37
	#6	3-14		#6	3-38
	#7	3-15		#7	3-39
	#8	3-16		#8	3-40
3.3 (Star #1187076)	#1	3-17	3.6 (Star #1187055)	#1	3-41
	#2	3-18		#2	3-42
	#3	3-19		#3	3-43
	#4	3-20		#4	3-44
	#5	3-21		#5	3-45
	#6	3-22			
	#7	3-23			
	#8	3-24			

Table 11. Coupler Interconnect Scheme (Third Floor)

Subnet Group (Star ID#)	Coupler port pair	Cable ID	Subnet Group (Star ID#)	Coupler port pair	Cable ID
4.1 (Star #0987002)	#1	4-1	4.4 (Star #1287189)	#1	4-25
	#2	4-2		#2	4-26
	#3	4-3		#3	4-27
	#4	4-4		#4	4-28
	#5	4-5		#5	4-29
	#6	4-6		#6	4-30
	#7	4-7		#7	4-31
	#8	4-8		#8	4-32
4.2 (Star #1187079)	#1	4-9	4.5 (Star #1187080)	#1	4-33
	#2	4-10		#2	4-34
	#3	4-11		#3	4-35
	#4	4-12		#4	4-36
	#5	4-13		#5	4-37
	#6	4-14		#6	4-38
	#7	4-15		#7	4-39
	#8	4-16		#8	4-40
4.3 (Star #1287186)	#1	4-17	4.6 (Star #1287192)	#1	4-41
	#2	4-18		#2	4-42
	#3	4-19		#3	4-43
	#4	4-20		#4	4-44
	#5	4-21		#5	4-45
	#6	4-22		#6	4-46
	#7	4-23			
	#8	4-24			

Table 12. Coupler Interconnect Scheme (Fourth Floor)

B.2 Transceiver Equipment

Transceiver Model	Wavelength	Location Room #(item count)	Description
Codenet C3051	830nm	Rooms 304(3),389,388,385	IBM PC/XT/AT Compatible 10mbs 802.3 Transceiver
Codenet C4350	n/a	Rooms 337(1)	Codenal 4300 series interconnect bus card for coax 10mbs 802.3 transmission
Codenet C4351	n/a	Room 337(2)	Codenal 4300 series interconnect bus card for thick-net 10mbs 802.3 transmission
Codenet C3030B	830nm	Rooms 337(2), 387(1)	External thick-net to 830nm transceiver. Conforms to 802.3 specifications.
Codenet C4300	various	Rooms 337(1)	Multi-media 802.3 repeater and interconnect unit. Operates at 10mbs.

Table 13. Transceiver Inventory

B.3 Miscellaneous Equipment

Equipment Name	Location {Room # (item count)}	Description
Equipment Rack	Rooms 142(1), 337(1), 437(1)	Customized Equipment Rack with front access and internal power strip

Table 14. Miscellaneous Equipment Locations

C. Network and Station Address Assignments

The Mohler Network physical layout has 143 nodes divided among 4 floors. Each node station has the potential of having a local connection site to a computer or Local Area Network. Proper Internet addresses and virtual node name assignments for each of the 143 nodes in the Mohler building will promote easy access to computing resources located on the Mohler LAN.

The following section describes in detail the internet address scheme and virtual node name assignments that are used for the Mohler Network.

C.1 Internet Address Scheme

Lehigh University has been designated as a class C internet user, with an assigned internet address range of 128.180.*.*. Communication access to the Mohler Network will be supported with a proteon router that has a 128.180.9.* class B slot address. This slot address range will allow each node station in the Mohler building to receive a separate internet address; 256 different address combinations are possible with the address convention assigned for this router slot. This will leave room for expansion since there will be about 150 total nodes in the entire building, including currently deployed Sun workstations and CAD system in the CIM Lab.

Each floor in the Mohler Building is assigned a specific range of possible internet addresses; these ranges are included in the following table.

Internet Address Range	Floor Covered	Nodes Assigned
128.180.9.[1-70]	First	40
128.180.9.[71-117]	Second	15
128.180.9.[118-187]	Third	52†
128.180.9.[188-256]	Fourth	46

Table 15. Internet Address Range Assignments

† These assigned nodes include 46 node stations having fiber optic cable connections to the LAN and 6 node stations having coaxial cable connections to the LAN.

C.2 Virtual Node Names and Node Functions

The following tables list the virtual node names and functions along with their internet address assignments on a floor-by-floor basis:

Port ID#	Room #	Virtual Node Name	Internet Address	Function
1-1	171	mantech1.mse.lehigh.edu	128.180.9.1	unassigned
1-2	171	mantech2.mse.lehigh.edu	128.180.9.2	unassigned
1-3	171	mantech3.mse.lehigh.edu	128.180.9.3	unassigned
1-4	171	mantech4.mse.lehigh.edu	128.180.9.4	unassigned
1-5	171	mantech5.mse.lehigh.edu	128.180.9.5	unassigned
1-6	171	mantech6.mse.lehigh.edu	128.180.9.6	unassigned
1-7	171	mantech7.mse.lehigh.edu	128.180.9.7	unassigned
1-8	171	mantech8.mse.lehigh.edu	128.180.9.8	unassigned
1-9	171	mantech9.mse.lehigh.edu	128.180.9.9	unassigned
1-10	171	mantech10.mse.lehigh.edu	128.180.9.10	unassigned
1-11	171	mantech11.mse.lehigh.edu	128.180.9.11	unassigned
1-12	171	mantech12.mse.lehigh.edu	128.180.9.12	unassigned
1-13	171A	mantech13.mse.lehigh.edu	128.180.9.13	unassigned
1-14	171A	mantech14.mse.lehigh.edu	128.180.9.14	unassigned
1-15	171A	mantech15.mse.lehigh.edu	128.180.9.15	unassigned
1-16	171	mantech16.mse.lehigh.edu	128.180.9.15	unassigned
1-17	110	N110R1.mse.lehigh.edu	128.180.9.16	unassigned
1-18	120	N120R1.mse.lehigh.edu	128.180.9.17	unassigned
1-19	110	N110R2.mse.lehigh.edu	128.180.9.18	unassigned
1-20	112	N112R1.mse.lehigh.edu	128.180.9.19	unassigned
1-21	146	N146R1.mse.lehigh.edu	128.180.9.20	unassigned
1-22	112	N112R2.mse.lehigh.edu	128.180.9.21	unassigned
1-23	142	N142R1.mse.lehigh.edu	128.180.9.22	unassigned
1-24	142	N142R2.mse.lehigh.edu	128.180.9.23	unassigned
1-25	110	N110R3.mse.lehigh.edu	128.180.9.24	unassigned
1-26	121	robotics1.mse.lehigh.edu	128.180.9.25	unassigned
1-27	121	robotics2.mse.lehigh.edu	128.180.9.26	unassigned
1-28	121	robotics3.mse.lehigh.edu	128.180.9.27	unassigned
1-29	121	robotics4.mse.lehigh.edu	128.180.9.28	unassigned
1-30	121A	robotics5.mse.lehigh.edu	128.180.9.29	unassigned
1-31	121	robotics6.mse.lehigh.edu	128.180.9.30	unassigned
1-32	121	robotics7.mse.lehigh.edu	128.180.9.31	unassigned
1-33	121	robotics8.mse.lehigh.edu	128.180.9.32	unassigned
1-34	121	robotics9.mse.lehigh.edu	128.180.9.33	unassigned
1-35	121	robitics10.mse.lehigh.edu	128.180.9.34	unassigned

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Port ID#	Room #	Virtual Node Name	Internet Address	Function
1-36	121	robotics11.mse.lehigh.edu	128.180.9.35	unassigned
1-37	121	robotics12.mse.lehigh.edu	128.180.9.36	unassigned
1-38	121	robotics13.mse.lehigh.edu	128.180.9.37	unassigned
1-39	121A	robotics14.mse.lehigh.edu	128.180.9.38	unassigned
1-40	121A	robotics15.mse.lehigh.edu	128.180.9.39	unassigned

Table 16. Logical Node Names and Functions for First Floor

Port ID#	Room #	Virtual Node Name	Internet Address	Function
2-1	210	cim1.mse.lehigh.edu	128.180.9.71	unassigned
2-2	210	cim2.mse.lehigh.edu	128.180.9.72	unassigned
2-3	210	cim3.mse.lehigh.edu	128.180.9.73	unassigned
2-4	210	cim4.mse.lehigh.edu	128.180.9.74	unassigned
2-5	210	cim5.mse.lehigh.edu	128.180.9.75	unassigned
2-6	210	cim6.mse.lehigh.edu	128.180.9.76	unassigned
2-7	210	cim7.mse.lehigh.edu	128.180.9.77	unassigned
2-8	210	cim8.mse.lehigh.edu	128.180.9.78	unassigned
2-9	206	N206R1.mse.lehigh.edu	128.180.9.79	unassigned
2-10	205	N205R1.mse.lehigh.edu	128.180.9.80	unassigned
2-11	204	N204R1.mse.lehigh.edu	128.180.9.81	unassigned
2-12	200	N200R1.mse.lehigh.edu	128.180.9.82	unassigned
2-13	201	N201R1.mse.lehigh.edu	128.180.9.83	unassigned
2-14	203	N203R1.mse.lehigh.edu	128.180.9.84	unassigned
2-15	203	N203R2.mse.lehigh.Edu	128.180.9.85	unassigned

Table 17. Logical Node Names and Functions for Second Floor

Port ID#	Room #	Virtual Node Name	Internet Address	Function
3-1	389	N389R1.mse.lehigh.edu	128.180.9.118	unassigned
3-2	380	N380R1.mse.lehigh.edu	128.180.9.119	unassigned
3-3	388	N388R1.mse.lehigh.edu	128.180.9.120	unassigned
3-4	380	N380R2.mse.lehigh.edu	128.180.9.121	unassigned
3-5	381	N380R1.mse.lehigh.edu	128.180.9.122	unassigned
3-6	385	N385R1.mse.lehigh.edu	128.180.9.123	unassigned
3-7	387	N387R1.mse.lehigh.edu	128.180.9.124	unassigned
3-8	375	N375R1.mse.lehigh.edu	128.180.9.125	unassigned
3-9	301	N301R1.mse.lehigh.edu	128.180.9.126	unassigned
3-10	301	N301R2.mse.lehigh.edu	128.180.9.127	unassigned
3-11	304	N304R1.mse.lehigh.edu	128.180.9.128	unassigned
3-12	304	N304R2.mse.lehigh.edu	128.180.9.128	unassigned
3-13	325	N304R1.mse.lehigh.edu	128.180.9.129	unassigned
3-14	323	N323R1.mse.lehigh.edu	128.180.9.130	unassigned
3-15	322	N322R1.mse.lehigh.edu	128.180.9.131	unassigned
3-16	321	N321R1.mse.lehigh.edu	128.180.9.132	unassigned
3-17	327	N327R1.mse.lehigh.edu	128.180.9.133	unassigned
3-18	304	N304R3.mse.lehigh.edu	128.180.9.134	unassigned
3-19	329	N329R1.mse.lehigh.edu	128.180.9.135	unassigned
3-20	320	N320R1.mse.lehigh.edu	128.180.9.136	unassigned
3-21	320	N320R2.mse.lehigh.edu	128.180.9.137	unassigned
3-22	320	N320R3.mse.lehigh.edu	128.180.9.138	unassigned
3-23	358	N358R1.mse.lehigh.edu	128.180.9.140	unassigned
3-24	371	N371R1.mse.lehigh.edu	128.180.9.141	unassigned
3-25	371	N371R2.mse.lehigh.edu	128.180.9.142	unassigned
3-26	371	N371R3.mse.lehigh.edu	128.180.9.143	unassigned
3-27	356	N356R1.mse.lehigh.edu	128.180.9.144	unassigned
3-28	356	N356R2.mse.lehigh.edu	128.180.9.145	unassigned
3-29	356	N356R3.mse.lehigh.edu	128.180.9.146	unassigned
3-30	358	N358R1.mse.lehigh.edu	128.180.9.147	unassigned
3-31	362	isl1.mse.lehigh.edu	128.180.9.148	unassigned
3-32	362	isl2.mse.lehigh.edu	128.180.9.149	unassigned
3-33	362	isl3.mse.lehigh.edu	128.180.9.150	unassigned
3-34	362	isl4.mse.lehigh.edu	128.180.9.151	unassigned
3-35	362	isl5.mse.lehigh.edu	128.180.9.152	unassigned

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Port ID#	Room #	Virtual Node Name	Internet Address	Function
3-36	362	isl6.mse.lehigh.edu	128.180.9.153	unassigned
3-37	355	N355R1.mse.lehigh.edu	128.180.9.154	unassigned
3-38	355	N355R2.mse.lehigh.edu	128.180.9.155	unassigned
3-39	355	N355R3.mse.lehigh.edu	128.180.9.156	unassigned
3-40	358	N358R2.mse.lehigh.edu	128.180.9.157	unassigned
3-41	353	N353R1.mse.lehigh.edu	128.180.9.158	unassigned
3-42	353	N353R2.mse.lehigh.edu	128.180.9.159	unassigned
3-43	342	N342R1.mse.lehigh.edu	128.180.9.160	unassigned
3-44	342	N342R2.mse.lehigh.edu	128.180.9.161	unassigned
3-45	342	N342R3.mse.lehigh.edu	128.180.9.162	unassigned
3-C1	362	islsun1.mse.lehigh.edu	128.180.9.163	Sun Workstation (mse mail host)
3-C1	362	islsun2.mse.lehigh.edu	128.180.9.164	Sun Workstation
3-C1	362	islsun3.mse.lehigh.edu	128.180.9.165	Sun Workstation
3-C1	362	islsun4.mse.lehigh.edu	128.180.9.166	Sun Workstation
3-C1	362	islsun5.mse.lehigh.edu	128.180.9.167	Sun Workstation
3-N1	337	admin3-1.mse.lehigh.edu	128.180.9.168	386 Novell S (IPX-IP Gateway/Mailer)
3-N2	337	mohler3-1.mse.lehigh.edu	128.180.9.169	386 Novell S

Table 18. Logical Node Names and Functions for Third Floor

Port ID#	Room #	Virtual Node Name	Internet Address	Function
4-1	484	N484R1.ie.lehigh.edu	128.180.9.188	unassigned
4-2	484	N484R2.ie.lehigh.edu	128.180.9.189	unassigned
4-3	486	N486R1.ie.lehigh.edu	128.180.9.190	unassigned
4-4	485	N485R1.ie.lehigh.edu	128.180.9.191	unassigned
4-5	479	N479R1.ie.lehigh.edu	128.180.9.192	unassigned
4-6	481	N481R1.ie.lehigh.edu	128.180.9.193	unassigned
4-7	444A	mirolab1.ie.lehigh.edu	128.180.9.194	unassigned
4-8	478	N478R1.ie.lehigh.edu	128.180.9.195	unassigned
4-9	444A	microlab2.ie.lehigh.edu	128.180.9.196	unassigned
4-10	401	N401R1.ie.lehigh.edu	128.180.9.197	unassigned
4-11	421A	N421R1.ie.lehigh.edu	128.180.9.198	unassigned
4-12	421	N421R2.ie.lehigh.edu	128.180.9.199	unassigned
4-13	421	N421R3.ie.lehigh.edu	128.180.9.200	unassigned
4-14	421	N421R4.ie.lehigh.edu	128.180.9.201	unassigned
4-15	421C	N421R5.ie.lehigh.edu	128.180.9.202	unassigned
4-16	429	N429R1.ie.lehigh.edu	128.180.9.203	unassigned
4-17	429	N429R2.ie.lehigh.edu	128.180.9.204	unassigned
4-18	477	N477R1.ie.lehigh.edu	128.180.9.205	unassigned
4-19	475	N475R1.ie.lehigh.edu	128.180.9.206	unassigned
4-20	475	N475R2.ie.lehigh.edu	128.180.9.207	unassigned
4-21	476	N476R1.ie.lehigh.edu	128.180.9.208	unassigned
4-22	473	N473R1.ie.lehigh.edu	128.180.9.209	unassigned
4-23	471	N471R1.ie.lehigh.edu	128.180.9.210	unassigned
4-24	472	N472R1.ie.lehigh.edu	128.180.9.211	unassigned
4-25	472	N472R2.ie.lehigh.edu	128.180.9.212	unassigned
4-26	453	infosys1.ie.lehigh.edu	128.180.9.213	unassigned
4-27	453	infosys2.ie.lehigh.edu	128.180.9.214	unassigned
4-28	453	infosys3.ie.lehigh.edu	128.180.9.215	unassigned
4-29	453	infosys4.ie.lehigh.edu	128.180.9.216	unassigned
4-30	453A	infosys5.ie.lehigh.edu	128.180.9.217	unassigned
4-31	453	infosys6.ie.lehigh.edu	128.180.9.218	unassigned
4-32	453A	infosys7.ie.lehigh.edu	128.180.9.219	unassigned
4-33	444	microlab3.ie.lehigh.edu	128.180.9.220	unassigned
4-34	444	microlab4.ie.lehigh.edu	128.180.9.221	unassigned
4-35	444	microlab5.ie.lehigh.edu	128.180.9.222	unassigned

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Port ID#	Room #	Virtual Node Name	Internet Address	Function
4-36	444	microlab6.ie.lehigh.edu	128.180.9.223	unassigned
4-37	444	microlab7.ie.lehigh.edu	128.180.9.224	unassigned
4-38	444	microlab8.ie.lehigh.edu	128.180.9.225	unassigned
4-39	451	worksys1.ie.lehigh.edu	128.180.9.226	unassigned
4-40	451	worksys2.ie.lehigh.edu	128.180.9.227	unassigned
4-41	451	worksys3.ie.lehigh.edu	128.180.9.228	unassigned
4-42	451	worksys4.ie.lehigh.edu	128.180.9.229	unassigned
4-43	451	worksys5.ie.lehigh.edu	128.180.9.230	unassigned
4-44	451A	worksys6.ie.lehigh.edu	128.180.9.231	unassigned
4-45	451A	worksys7.ie.lehigh.edu	128.180.9.232	unassigned
4-46	451	worksys8.ie.lehigh.edu	128.180.9.233	unassigned

Table 19. Logical Node Names and Functions for Fourth Floor

D. Physical Medium Characterization Data

The following three sections include characterization data for the PFCs used in the Mohler LAN. The first section lists OTDR length measurements for the optical fiber cables installed in the Mohler building. The second section includes power attenuation measurements taken for these optical fiber cables. The third section characterizes the AMP $16X16$ optical star-couplers.

D.1 Optical Fiber Length Measurements

A Tektronix OF-150 Optical Time Domain Reflectometer (OTDR) was used to measure optical fiber cable lengths for each of the 143 passive taps in the Mohler Building. Measurements on each of the optical fiber cables were made at 830nm for better length resolution. The measurement procedure consists of introducing optical pulses into one end of a fiber cable. The OTDR sends a pulse of energy into the fiber core and "listens" for any reflections. The time delay between pulse launch and reflection detection is used to determine how far the optical energy has traveled.

The Tektronix OF-150 OTDR has an inherent propagation delay in its electronic circuitry, thus limiting its response time in detecting return reflections. This delay time corresponds to approximately 50 meters of multimode fiber. A leader, of at least this length, was spliced onto the fiber that is to be measured. This leader eliminates the possibility of having length measurements fall into the OTDR's **dead zone**. To avoid any problems with the OTDR, 253 meters of leader fiber was spliced into each fiber tap before the length measurement was taken. This was to insure optimum length resolution from the OTDR.

Length measurements were taken for all 143 nodes in the Mohler LAN with with ± 1 meter resolution and are presented in tabular format on a floor-by-floor basis. At the time this this was written, fiber optic installation on the second floor in the Mohler building had not been completed. Optical fiber cables and FSD wall outlets for the 15 node stations on the second floor are not completely installed. Length measurements for these nodes are denoted by an **xx**. Also, there are a few nodes on the first, third and fourth floors which have length measurements denoted by an **xx**. The fiber connectors at these nodes were found to be defective when the OTDR measurements were taken. The connectors were subsequently replaced and are now ready to be measured again with the OTDR. The fibers at these nodes are good, because each were verified for continuity by shining a light into one end of the fiber connector and visually inspecting the other end.

OTDR Length measurements are included for each separate floor in the Mohler Building:

OTDR Measurements

Cable ID#	Starting Room	Ending Room	Start Terminator type	End Terminator type	Length (meters)
1-1	142	171	ST	FSD	56
1-2	142	171	ST	FSD	51
1-3	142	171	ST	FSD	45
1-4	142	171	ST	FSD	41
1-5	142	171	ST	FSD	36
1-6	142	171	ST	FSD	50
1-7	142	171	ST	FSD	53
1-8	142	171	ST	FSD	58
1-9	142	171	ST	FSD	73
1-10	142	171	ST	FSD	73
1-11	142	171	ST	FSD	52
1-12	142	171	ST	FSD	44
1-13	142	171A	ST	FSD	45
1-14	142	171A	ST	FSD	46
1-15	142	171A	ST	FSD	46
1-16	142	171	ST	FSD	36
1-17	142	110	ST	FSD	40
1-18	142	120	ST	FSD	xx
1-19	142	110	ST	FSD	35
1-20	142	112	ST	FSD	35
1-21	142	146	ST	FSD	xx
1-22	142	112	ST	FSD	34
1-23	142	142	ST	FSD	xx
1-24	142	142	ST	FSD	xx
1-25	142	110	ST	FSD	29
1-26	142	121	ST	FSD	34
1-27	142	121	ST	FSD	30
1-28	142	121	ST	FSD	xx
1-29	142	121	ST	FSD	xx
1-30	142	121A	ST	FSD	xx
1-31	142	121	ST	FSD	xx
1-32	142	121	ST	FSD	34
1-33	142	121	ST	FSD	31
1-34	142	121	ST	FSD	24
1-35	142	121	ST	FSD	18

(continued on next page . . .)

OTDR Measurements

Cable ID#	Starting Room	Ending Room	Start Terminator type	End Terminator type	Length (meters)
1-36	142	121	ST	FSD	xx
1-37	142	121	ST	FSD	35
1-38	142	121	ST	FSD	xx
1-39	142	121A	ST	FSD	xx
1-40	142	121A	ST	FSD	xx

Table 20. OTDR Measurements for First Floor

OTDR Measurements

Cable ID#	Starting Room	Ending Room	Start Terminator type	End Terminator type	Length (meters)
2-1	142	210	ST	FSD	29
2-2	142	210	ST	FSD	xx
2-3	142	210	ST	FSD	xx
2-4	142	210	ST	FSD	xx
2-5	142	210	ST	FSD	xx
2-6	142	210	ST	FSD	xx
2-7	142	210	ST	FSD	xx
2-8	142	210	ST	FSD	xx
2-9	142	206	ST	FSD	xx
2-10	142	205	ST	FSD	xx
2-11	142	204	ST	FSD	xx
2-12	142	200	ST	FSD	xx
2-13	142	201	ST	FSD	xx
2-14	142	203	ST	FSD	xx
2-15	142	203	ST	FSD	xx

Table 21. OTDR Measurements for Second Floor

OTDR Measurements

Cable ID#	Starting Room	Ending Room	Start Terminator type	End Terminator type	Length (meters)
3-1	337	389	ST	FSD	29
3-2	337	380	ST	FSD	46
3-3	337	388	ST	FSD	48
3-4	337	380	ST	FSD	21
3-5	337	381	ST	FSD	55
3-6	337	385	ST	FSD	42
3-7	337	387	ST	FSD	56
3-8	337	375	ST	FSD	71
3-9	337	301	ST	FSD	56
3-10	337	301	ST	FSD	49
3-11	337	304	ST	ST	35
3-12	337	304	ST	ST	35
3-13	337	325	ST	FSD	41
3-14	337	323	ST	FSD	46
3-15	337	322	ST	FSD	39
3-16	337	321	ST	FSD	39
3-17	337	327	ST	FSD	37
3-18	337	304	ST	FSD	29
3-19	337	329	ST	FSD	23
3-20	337	320	ST	FSD	34
3-21	337	320	ST	FSD	29
3-22	337	320	ST	FSD	26
3-23	337	358	ST	FSD	42
3-24	377	371	ST	FSD	41
3-25	337	371	ST	FSD	46
3-26	337	371	ST	FSD	50
3-27	337	356	ST	FSD	xx
3-28	337	356	ST	FSD	xx
3-29	337	356	ST	FSD	58
3-30	337	358	ST	FSD	xx
3-31	337	362	ST	FSD	40
3-32	337	362	ST	FSD	46
3-33	337	362	ST	FSD	63
3-34	337	362	ST	FSD	28
3-35	337	362	ST	FSD	36

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OTDR Measurements

Cable ID#	Starting Room	Ending Room	Start Terminator type	End Terminator type	Length (meters)
3-36	337	362	ST	FSD	40
3-37	337	355	ST	FSD	47
3-38	337	355	ST	FSD	61
3-39	337	355	ST	FSD	64
3-40	337	358	ST	FSD	28
3-41	337	353	ST	FSD	xx
3-42	337	353	ST	FSD	42
3-43	337	342	ST	FSD	28
3-44	337	342	ST	FSD	28
3-45	337	342	ST	FSD	xx
3-C1	337	362	BNC (RG58 coax)	BNC (RG58 coax)	33
3-N1	337	337	ST	ST	1
3-N2	337	337	ST	ST	1

Table 22. OTDR Measurements for Third Floor

OTDR Measurements

Cable ID#	Starting Room	Ending Room	Start Terminator type	End Terminator type	Length (meters)
4-1	142	484	ST	FSD	60
4-2	437	483	ST	FSD	60
4-3	437	486	ST	FSD	56
4-4	437	485	ST	FSD	69
4-5	437	479	ST	FSD	53
4-6	437	481	ST	FSD	56
4-7	437	444A	ST	FSD	xx
4-8	437	478	ST	FSD	56
4-9	437	444A	ST	FSD	xx
4-10	437	401	ST	FSD	43
4-11	437	421A	ST	FSD	45
4-12	437	421	ST	FSD	44
4-13	437	421	ST	FSD	45
4-14	437	421	ST	FSD	xx
4-15	437	421C	ST	FSD	43
4-16	437	429	ST	FSD	30
4-17	437	429	ST	FSD	xx
4-18	437	477	ST	FSD	52
4-19	437	475	ST	FSD	53
4-20	437	476	ST	FSD	xx
4-21	437	476	ST	FSD	xx
4-22	437	473	ST	FSD	50
4-23	437	471	ST	FSD	49
4-24	437	472	ST	FSD	41
4-25	437	472	ST	FSD	41
4-26	437	453	ST	FSD	43
4-27	437	453	ST	FSD	43
4-28	437	453	ST	FSD	38
4-29	437	453	ST	FSD	xx
4-30	437	453A	ST	FSD	26
4-31	437	453	ST	FSD	36
4-32	437	453A	ST	FSD	26
4-33	437	444	ST	FSD	30
4-34	437	444	ST	FSD	43
4-35	437	444	ST	FSD	42

(continued on next page . . .)

OTDR Measurements

Cable ID#	Starting Room	Ending Room	Start Terminator type	End Terminator type	Length (meters)
4-36	437	444	ST	FSD	36
4-37	437	444	ST	FSD	xx
4-38	437	444	ST	FSD	32
4-39	437	451	ST	FSD	xx
4-40	437	451	ST	FSD	xx
4-41	437	451	ST	FSD	30
4-42	437	451	ST	FSD	35
4-43	437	451	ST	FSD	25
4-44	437	451A	ST	FSD	23
4-45	437	451A	ST	FSD	22
4-46	437	451	ST	FSD	xx

Table 23. OTDR Measurements for Fourth Floor

D.2 Fiber Attenuation Measurements

A Laser Precision Power meter and source was used to determine fiber losses. Two multimode sources were used; one was rated for transmission at 830nm CW wavelength; the other source was rated for 1300nm CW wavelength. Loss measurements were taken by sending optical energy down each of the fibers in the Mohler building. Energy readings were then taken at other end with the power meter. The procedure involved taking power loss measurements at both wavelengths for each node in the Mohler building. Figure 30 illustrates the loss measuring procedure.

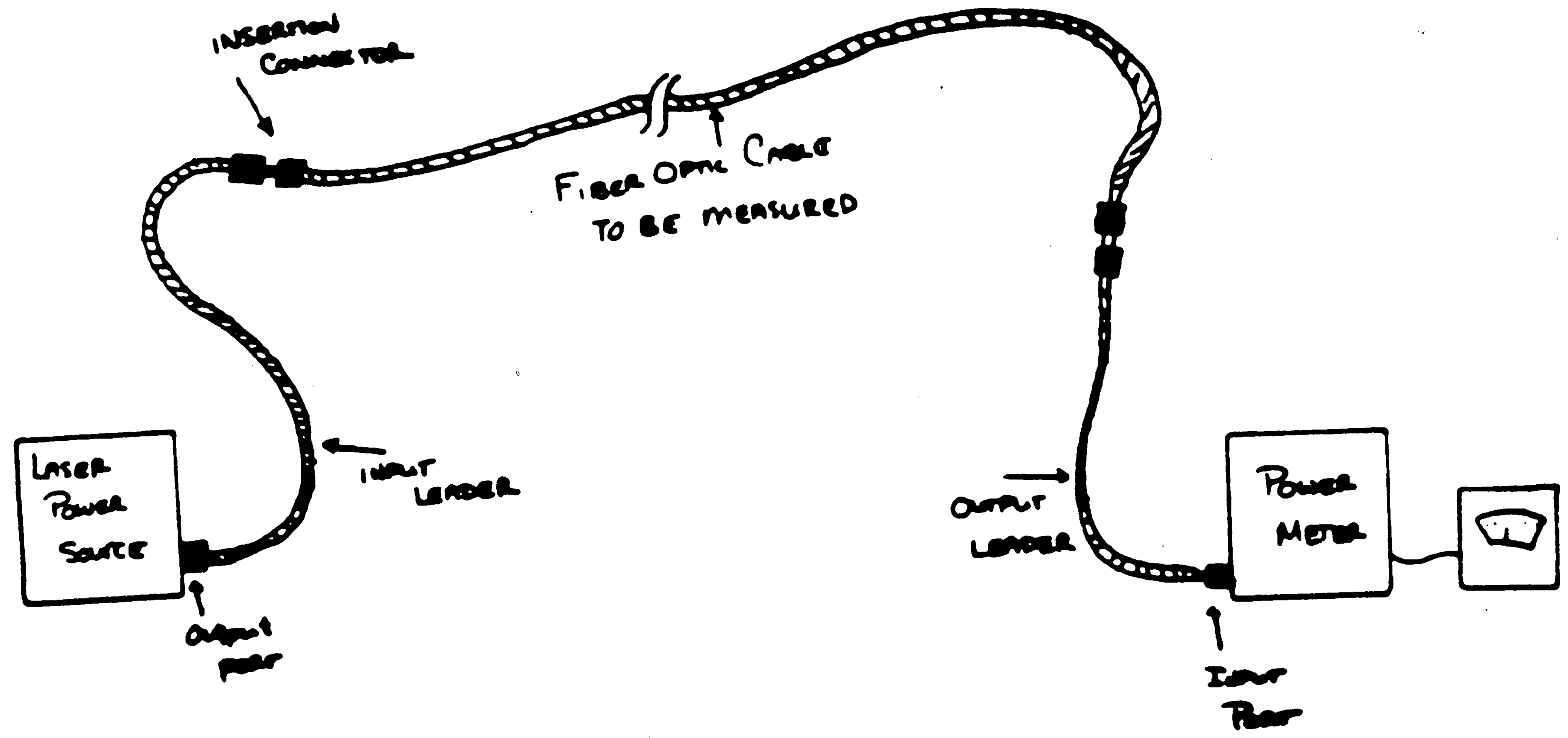

Figure 30. Fiber Attenuation Measurement Setup

The figure shows a power source and meter connected with a fiber link. The link is comprised of three sections of optical fiber cable — an input leader cable, a test cable and an output leader cable. The test cable corresponds to the section of fiber which attenuation measurements are to be taken from. The input and output leader fibers are used to permit maneuverability of the power source and meter when taking the measurements. Data readings from the power meter consist of the total serial loss between the source and meter. It is necessary to subtract the loss contributions of the input and output leaders, along with losses introduced by their connectors, from the readings obtained for the entire fiber link. The corrected reading excludes loss contributions from the input and output leader fibers.

The following power loss calculations are presented on a by-floor basis. All data values include insertion losses for an **FSD** and **ST** connector along with fiber losses. It is important to realize that most power loss in the fiber link is caused by the connectors placed at each end of the fiber, not the fiber itself. Each fiber has, at the most, 0.05dB of attenuation; this is a direct consequence of chromatic dispersion. The connectors contribute the remaining loss. The tables of power loss calculations are arranged in tabular format. Values are given for both transmit (white) and receive (black) fibers at each wavelength. The maximum power loss value found for either (transmit or receive) fiber was used to obtain an maximum fiber link loss value. This piece of data is used to characterized the entire link loss for the physical layout in section 2.

At the time this thesis was written, the second floor in the Mohler building was not completed. Optical fiber cables and FSD wall outlets for the 15 node stations on the second floor are not completely installed. Fiber attenuation measurements for these nodes are denoted by **xx** and **yy** for 830*nm* and 1300*nm* respectively. Also, there are a few nodes on the first, third and fourth floors which have attenuation measurements denoted by either an **xx** or **yy**. The fiber connectors at these nodes were found to be defective when the loss measurements were taken. The connectors were subsequently replaced and are now ready to be measured again with the loss measurement setup shown in figure 30. The fibers at these nodes are good, because each was verified for continuity by shining a light into one end of the fiber connector and visually inspecting the other end of the fiber.

Room	Cable ID#	830nm black fiber (transmit)	830nm white fiber (receive)	1300nm black fiber (transmit)	1300nm white fiber (receive)	Maximum Link Loss
110	1-17	1.6	2.5	0.1	0.1	2.5
	1-19	1.6	2.3	0.1	0.1	2.3
112	1-20	2.8	2.9	0.1	0.1	2.9
	1-22	2.0	2.2	0.1	0.1	2.2
120	1-18	xx	xx	yy	yy	tbd†
121	1-26	1.4	1.7	0.1	0.1	1.7
	1-27	1.6	2.1	0.5	0.3	2.1
	1-28	1.6	1.7	0.1	0.4	1.7
	1-29	1.8	1.8	0.7	0.1	1.8
	1-31	1.7	1.8	0.1	0.1	1.8
	1-32	2.1	2.4	0.1	0.1	2.4
	1-33	1.8	1.9	0.1	1.1	1.9
	1-34	1.9	1.7	0.8	0.7	1.9
	1-35	1.5	1.6	0.9	0.2	1.6
	1-36	xx	xx	yy	yy	tbd
	1-37	xx	xx	yy	yy	tbd
	1-38	xx	xx	yy	yy	tbd
121A	1-30	xx	xx	yy	yy	tbd
	1-39	xx	xx	yy	yy	tbd
	1-40	xx	xx	yy	yy	tbd
171	1-1	2.3	2.0	0.1	0.1	2.3
	1-2	2.3	2.5	0.1	0.1	2.5
	1-3	2.6	1.6	0.2	0.1	2.6
	1-4	0.1	2.1	0.1	0.1	2.1
	1-5	xx	xx	yy	yy	tbd
	1-6	xx	xx	yy	yy	tbd
	1-7	xx	xx	yy	yy	tbd
	1-8	xx	xx	yy	yy	tbd
	1-9	3.0	2.2	2.2	2.5	3.0
	1-10	1.6	2.0	0.9	1.4	2.0
	1-11	1.6	1.6	0.8	0.8	1.6
	1-12	2.9	2.0	1.6	0.7	2.9
	1-16	xx	0.1	2.8	1.7	tbd
171A	1-13	1.6	2.1	3.2	0.2	3.2
	1-14	2.2	2.1	0.8	0.1	2.2
	1-15	1.9	1.5	0.1	0.1	1.9

Table 24. Fiber Attenuation Measurements (*First Floor*)

Room	Cable ID#	830nm black fiber (transmit)	830nm white fiber (receive)	1300nm black fiber (transmit)	1300nm white fiber (receive)	Maximum Link Loss
200	2-12	xx	xx	yy	yy	tbd
201	2-13	xx	xx	yy	yy	tbd
203	2-14	xx	xx	yy	yy	tbd
	2-15	xx	xx	yy	yy	tbd
204	2-11	xx	xx	yy	yy	tbd
205	2-10	xx	xx	yy	yy	tbd
206	2-9	xx	xx	yy	yy	tbd
210	2-1	xx	xx	yy	yy	tbd
	2-2	xx	xx	yy	yy	tbd
	2-3	xx	xx	yy	yy	tbd
	2-4	xx	xx	yy	yy	tbd
	2-5	xx	xx	yy	yy	tbd
	2-6	xx	xx	yy	yy	tbd
	2-7	xx	xx	yy	yy	tbd
	2-8	xx	xx	yy	yy	tbd

Table 25. Fiber Attenuation Measurements (*Second Floor*)

† tbd — to be determined (maximum measured loss for transmit and receive cables at 830*nm* or 1300*nm*.)

Room	Cable ID#	830nm black fiber (transmit)	830nm white fiber (receive)	1300nm black fiber (transmit)	1300nm white fiber (receive)	Maximum Link Loss
301	3-9	2.8	2.9	1.3	1.4	2.9
	3-10	2.6	2.8	0.1	0.4	2.8
304	3-11	1.5	0.7	0.7	0.1	1.5
	3-12	0.1	0.7	0.1	0.1	0.7
	3-18	2.7	3.0	0.7	0.1	3.0
320	3-20	2.7	1.1	yy	0.1	tbd
	3-21	0.5	xx	0.1	yy	tbd
	3-22	1.1	1.1	0.4	0.4	1.1
321	3-16	1.8	2.2	0.2	0.2	2.2
322	3-15	xx	2.8	2.8	0.6	tbd
323	3-14	3.0	2.6	1.3	0.7	2.6
325	3-13	3.6	2.2	0.7	0.5	3.6
327	3-17	2.3	2.2	0.8	1.3	2.3
329	3-19	3.7	1.2	2.2	0.3	3.7
342	3-43	0.4	0.5	1.3	2.2	2.2
	3-44	0.7	0.5	0.5	2.7	2.7
	3-45	0.9	0.2	0.3	1.7	1.7
353	3-41	xx	xx	yy	yy	tbd
	3-42	xx	xx	yy	yy	tbd
355	1-37	0.8	1.2	0.9	1.4	1.4
	1-38	1.0	0.9	1.7	1.4	1.7
	1-39	1.4	0.9	1.0	1.2	1.4
356	3-27	2.5	4.3	0.6	4.1	4.3
	3-28	0.7	xx	1.2	8.5	tbd
	3-29	1.3	1.6	1.2	1.0	1.6
358	3-23	0.6	0.3	0.6	0.9	0.9
	3-30	xx	0.8	20.2	1.9	tbd
	3-40	0.3	0.8	0.1	1.1	1.1
362	3-31	xx	1.3	yy	2.2	tbd
	3-32	2.0	11.7	1.2	12.4	tbd
	3-33	xx	0.7	yy	0.6	tbd
	3-34	0.9	xx	1.0	yy	tbd
	3-35	0.2	1.2	0.2	0.9	1.2
	3-36	0.6	1.2	1.1	0.9	1.2

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Room	Cable ID#	830nm black fiber (transmit)	830nm white fiber (receive)	1300nm black fiber (transmit)	1300nm white fiber (receive)	Maximum Link Loss
371	3-24	0.7	0.4	1.0	0.5	1.0
	3-25	0.9	0.6	0.7	0.8	0.9
	3-26	xx	xx	yy	yy	tbd
375	3-8	2.9	xx	1.8	4.5	tbd
380	3-2	1.2	1.6	0.7	0.5	1.6
	3-4	1.3	1.8	0.4	1.5	1.8
381	3-5	0.9	1.3	0.1	0.3	1.3
385	3-6	1.8	1.8	0.7	1.6	1.8
387	3-7	xx	0.7	yy	0.4	tbd
388	3-3	1.1	1.2	0.5	1.0	1.2
389	3-1	1.6	0.9	1.2	1.3	1.6

Table 26. Fiber Attenuation Measurements (*Third Floor*)

Room	Cable ID#	830nm black fiber (transmit)	830nm white fiber (receive)	1300nm black fiber (transmit)	1300nm white fiber (receive)	Maximum Link Loss
401	4-10	3.1	2.5	3.3	3.1	3.3
421	4-12	3.7	2.3	4.0	2.6	4.0
	4-13	xx	xx	yy	yy	tbd
	4-14	xx	xx	yy	yy	tbd
421A	4-11	4.0	2.9	4.1	3.1	4.1
421C	4-15	3.1	3.1	3.5	3.4	3.5
429	4-16	2.4	2.4	2.7	3.0	3.0
	4-17	3.3	2.7	2.7	2.2	3.3
444	4-33	2.1	xx	2.4	yy	tbd
	4-34	2.6	1.8	2.9	2.4	2.9
	4-35	3.1	2.8	3.6	2.6	3.6
	4-36	2.1	2.7	2.6	2.6	2.7
	4-37	xx	xx	yy	yy	tbd
	4-38	2.7	2.9	2.7	2.8	2.9
444A	4-7	xx	xx	yy	yy	tbd
	4-9	xx	xx	yy	yy	tbd
451	4-39	xx	xx	yy	yy	tbd
	4-40	xx	xx	yy	yy	tbd
	4-41	3.2	xx	2.2	yy	tbd
	4-42	1.6	2.7	1.9	2.1	2.7
	4-43	2.7	2.4	1.9	1.9	2.7
	4-46	xx	xx	yy	yy	tbd
451A	4-44	1.7	3.0	1.3	2.5	3.0
	4-45	xx	2.6	yy	2.3	tbd
453	4-26	2.5	3.3	2.6	3.4	3.4
	4-27	2.7	2.6	2.4	2.4	2.7
	4-28	2.5	xx	2.5	yy	tbd
	4-29	xx	xx	yy	yy	tbd
	4-31	2.5	2.6	2.1	2.6	2.6
453A	4-30	0.1	2.6	2.3	2.4	2.6
	4-32	1.8	3.9	2.2	3.5	3.9
471	4-23	3.0	2.7	2.6	2.6	3.0
472	4-24	2.4	2.8	3.0	2.9	3.0
	4-25	2.1	2.5	2.3	2.6	2.6
473	4-22	2.0	xx	2.4	yy	tbd
475	4-19	xx	2.3	yy	3.0	tbd
	4-20	xx	xx	yy	yy	tbd

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Room	Cable ID#	830nm black fiber (transmit)	830nm white fiber (receive)	1300nm black fiber (transmit)	1300nm white fiber (receive)	Maximum Link Loss
476	4-21	2.1	3.2	2.8	3.3	3.3
477	4-18	2.7	2.6	2.2	2.7	2.7
478	4-8	xx	yy	xx	yy	tbd
479	4-5	2.2	2.5	2.8	3.0	3.0
481	4-6	2.6	3.3	2.2	2.7	3.3
484	4-1	xx	2.8	yy	3.2	tbd
	4-2	2.6	3.8	3.0	4.0	4.0
485	4-4	4.1	4.0	4.3	4.5	4.5
486	4-3	3.5	2.9	3.1	3.5	3.5

Table 27. Fiber Attenuation Measurements (*Fourth Floor*)

D.3 Coupler Loss Characterization

AMP Incorporated donated nineteen 16 X 16 biconically tapered optical couplers. The couplers are made of 62.5/125μm multimode fiber with 32 ST-type insertion connectors spliced onto their ports. Sixteen ports serve as input connections, while sixteen other ports serve as output connections.

Optical couplers are characterized by their effective input-to-output port power loss, loss uniformity between each of their ports and feedback (crosstalk) attenuation between each of the input ports. An ideal coupler should have perfectly uniform power separation among its output ports when power is introduced into any input port. No crosstalk or feedback should exist between any of the coupler inputs.

Three sections follow. The first section lists each of the nineteen AMP couplers by serial number. Input-to-output port power loss measurements were taken at 830nm for all port combinations, because the couplers exhibit greater loss at 830nm than they do at 1300nm. Each 16 X 16 coupler is characterized by a full loss matrix of power attenuation values. The second section gives Input-to-input port isolation loss data for each of the nineteen couplers. Isolation loss measurements were taken at 1300nm for the couplers because they couple more energy back into their input ports at 1300nm than they do at 830nm. The losses are listed for each of the sixteen ports on every coupler. Each loss value represents an average isolation loss for an input port. A power meter is connected to a specific input port, then an optical source is connected successively to the remaining 15 input ports. Isolation loss readings are then taken for each of the 15 source connections. These values are then averaged together to form an isolation loss value for that port. The isolation loss data is arranged by input port number and coupler serial number. The third section summarizes the coupler loss data detailed in the previous two sections. Maximum, minimum and average losses are given for each coupler with respect to input-to-output and input-to-input losses. *Note that all data values presented in all three sections are given in decibels (dB) of optical power loss measured between two coupler ports.* Power loss measurements were taken on Laser Precision equipment calibrated for both 830nm and 1300nm. All the loss measurements include insertion losses for each of the coupler port connectors.

D.3.1 Input-to-Output Port Loss Data

16 X 16 Optical Coupler Power Losses (dB)

Input Port	Output Port 1	2	3	4	5	6	7	8
1	15.6	15.6	15.0	15.7	15.5	15.8	15.0	15.5
2	15.4	15.3	13.3	15.3	15.0	15.5	14.6	15.2
3	14.6	14.4	13.9	14.6	14.2	14.7	13.9	14.4
4	14.8	14.6	14.1	14.8	14.4	15.0	14.1	13.2
5	14.4	14.1	13.7	14.3	13.9	14.5	13.7	14.3
6	14.1	13.9	13.5	14.0	13.6	14.3	13.4	14.0
7	14.7	13.8	14.1	14.7	14.3	14.9	14.0	14.7
8	13.6	14.5	14.0	14.6	14.2	14.9	13.8	14.6
9	14.3	14.1	13.7	14.1	13.8	14.5	13.6	14.3
10	14.6	14.4	13.9	14.4	14.1	14.7	13.8	14.5
11	14.6	14.3	13.9	14.6	14.4	14.6	13.9	14.4
12	15.0	15.0	14.4	15.1	14.7	15.3	13.4	15.1
13	14.8	14.5	14.1	14.7	14.3	14.3	14.0	14.7
14	14.7	14.5	14.0	14.7	14.3	14.9	13.6	14.7
15	14.7	14.4	14.0	14.7	14.2	14.6	14.0	14.6
16	14.6	14.3	13.9	14.6	14.1	14.6	13.9	14.5

Input Port	Output Port 9	10	11	12	13	14	15	16
1	15.1	15.7	15.9	15.3	13.8	15.1	15.6	15.5
2	14.6	15.4	15.5	15.0	14.8	14.8	15.3	15.3
3	14.0	14.6	14.7	13.3	14.0	14.0	14.5	14.4
4	14.1	14.8	15.0	14.4	14.2	14.2	14.7	14.7
5	13.7	14.4	14.5	14.1	13.9	13.7	14.2	14.3
6	13.5	14.1	14.3	13.8	13.7	13.5	13.9	14.0
7	14.1	14.7	14.9	14.4	14.3	14.1	14.6	14.6
8	14.0	14.7	14.9	14.4	14.2	14.1	14.5	14.6
9	13.8	14.4	14.5	14.0	13.9	13.7	14.0	14.2
10	14.1	14.6	14.7	14.3	14.1	13.9	14.3	14.5
11	14.1	13.9	14.7	14.2	14.1	13.9	14.4	14.3
12	14.3	15.2	15.4	14.9	14.7	14.6	15.0	15.1
13	14.3	14.7	14.8	14.3	14.3	14.1	14.6	14.5
14	13.4	14.8	14.9	14.4	14.3	14.1	14.6	14.6
15	14.2	14.5	14.8	14.2	14.1	14.0	14.5	13.9
16	14.1	14.5	14.7	14.2	14.1	13.9	14.4	14.4

Table 28. Optical Star Coupler #1187054 Loss Data

16 X 16 Optical Coupler Power Losses (dB)

Input Port	Output Port 1	2	3	4	5	6	7	8
1	14.0	14.2	13.8	13.9	14.0	13.8	13.9	14.0
2	14.0	14.2	13.8	13.9	14.3	13.8	14.1	14.3
3	14.5	14.9	14.6	14.1	14.9	14.4	14.4	14.0
4	14.0	13.9	13.8	13.9	14.0	13.8	13.9	14.0
5	14.0	14.9	14.6	13.9	14.0	13.8	13.9	14.0
6	14.0	14.4	14.0	13.9	14.1	13.8	13.9	14.1
7	14.0	14.6	14.6	13.8	14.9	13.8	14.6	14.3
8	14.0	14.9	14.8	14.5	14.9	14.6	14.4	14.7
9	14.0	14.4	14.0	13.9	14.0	13.8	13.9	14.0
10	14.0	14.9	14.0	14.1	14.5	14.0	14.2	14.5
11	14.0	14.9	14.0	13.9	14.3	13.8	13.9	14.5
12	14.1	14.9	14.8	14.5	14.9	14.2	14.9	14.9
13	14.0	14.9	14.0	13.9	14.9	13.8	14.2	14.3
14	14.5	14.9	14.8	14.3	14.9	14.4	14.6	14.9
15	14.0	14.4	13.8	13.9	14.0	13.8	13.9	14.0
16	14.7	14.9	14.8	14.9	14.9	14.4	13.9	14.9

Input Port	Output Port 9	10	11	12	13	14	15	16
1	13.1	13.9	14.6	13.9	14.0	13.9	14.0	14.0
2	13.1	13.9	14.6	13.9	14.0	13.9	14.0	14.0
3	13.9	14.3	14.9	14.1	14.3	14.7	14.9	14.9
4	13.7	13.9	14.4	13.9	14.0	13.9	14.0	14.0
5	13.9	13.9	14.9	13.9	14.0	13.9	14.1	14.0
6	13.9	13.9	14.9	13.9	14.0	13.9	14.0	14.0
7	13.9	14.3	14.9	13.9	14.0	13.9	14.7	14.9
8	13.9	14.7	14.9	14.3	14.5	14.7	14.7	14.9
9	13.9	14.3	14.6	13.9	14.0	13.9	14.0	14.0
10	13.9	14.3	14.9	13.9	14.1	13.9	14.0	14.1
11	13.9	13.9	14.6	13.9	14.0	13.9	14.0	14.0
12	13.9	13.9	14.9	14.1	14.7	14.7	14.9	14.9
13	13.9	13.9	14.9	13.9	14.0	14.1	14.7	14.9
14	13.9	14.9	14.9	14.5	14.5	13.9	14.9	14.9
15	13.5	13.9	14.1	13.9	13.8	13.9	14.0	14.0
16	13.9	14.9	14.9	14.3	14.7	14.9	14.9	14.9

Table 29. Optical Star Coupler #1187078 Loss Data

16 X 16 Optical Coupler Power Losses (dB)

Output Port

Input Port	1	2	3	4	5	6	7	8
1	14.0	13.9	13.8	13.9	13.8	13.8	13.9	14.0
2	14.5	13.9	13.8	13.9	14.0	13.8	13.9	14.0
3	14.9	13.9	13.8	13.9	14.0	13.8	13.9	14.0
4	14.0	13.1	13.8	13.9	13.3	13.8	13.4	14.0
5	14.9	13.9	14.0	13.9	14.0	14.0	13.9	14.1
6	14.9	14.2	14.8	14.1	14.0	14.0	14.4	14.5
7	14.0	13.9	13.8	13.9	13.2	13.8	13.9	14.0
8	14.0	13.1	13.8	13.9	13.2	13.5	13.1	13.2
9	14.0	13.7	13.8	13.9	13.6	13.8	13.1	13.3
10	14.1	13.9	13.8	13.9	14.0	13.8	13.9	14.0
11	14.0	13.9	13.8	13.9	13.3	13.8	13.9	14.0
12	14.0	13.5	13.5	13.3	13.2	13.8	13.1	13.3
13	14.9	13.9	13.8	14.3	14.0	13.8	13.9	14.0
14	14.3	13.9	13.8	13.9	14.0	13.8	13.9	14.0
15	14.0	13.9	13.8	13.9	13.3	13.8	13.9	13.5
16	14.0	13.9	13.8	13.9	13.5	13.2	13.9	14.0

Output Port

Input Port	9	10	11	12	13	14	15	16
1	13.5	13.9	13.5	13.9	14.0	13.9	14.0	14.0
2	13.9	13.9	13.9	13.9	13.3	13.9	14.0	14.0
3	13.9	13.9	13.7	13.9	14.0	13.9	14.0	14.0
4	13.4	13.9	13.2	13.8	13.3	13.9	13.6	14.0
5	13.9	13.9	13.9	13.9	14.0	13.9	14.0	14.1
6	13.9	14.7	13.9	13.9	14.0	14.5	14.0	14.9
7	13.1	13.9	13.7	13.4	13.8	13.9	14.0	13.3
8	13.1	13.8	13.1	13.3	13.2	13.3	13.2	14.0
9	13.2	13.9	13.2	13.8	13.8	13.9	13.8	14.0
10	13.2	13.9	13.9	13.9	14.0	13.9	14.0	14.0
11	13.2	13.4	13.4	13.9	14.0	13.9	14.0	14.0
12	13.1	13.9	13.1	13.1	13.3	13.1	13.2	13.8
13	13.9	13.9	13.9	13.9	14.0	13.9	14.0	14.3
14	13.9	13.9	13.9	13.9	14.0	13.9	14.0	14.3
15	13.7	13.9	13.5	13.9	13.8	13.9	14.0	14.0
16	13.2	13.9	13.4	13.9	13.5	13.9	13.8	14.0

Table 30. Optical Star Coupler #1187072 Loss Data

16 X 16 Optical Coupler Power Losses (dB)

Output Port

Input Port	1	2	3	4	5	6	7	8
1	13.9	14.8	14.5	15.0	14.6	14.4	14.7	14.6
2	14.4	13.5	14.0	14.7	14.4	14.1	14.9	14.2
3	14.2	15.0	14.8	15.2	14.7	14.6	14.3	14.7
4	13.9	14.1	14.0	14.3	12.9	13.7	14.4	13.7
5	14.0	14.3	14.2	14.2	14.1	13.8	14.5	14.0
6	13.9	14.1	14.1	14.2	14.1	12.8	14.4	13.8
7	14.5	14.7	14.7	14.8	14.7	14.3	14.9	14.4
8	14.5	14.8	14.7	14.7	14.7	14.2	15.1	14.4
9	13.9	13.8	13.0	14.3	14.1	13.7	14.5	13.8
10	14.5	14.6	14.5	14.8	14.6	14.2	15.0	14.3
11	14.1	14.3	14.3	14.6	14.2	14.0	14.6	14.0
12	14.1	14.3	14.1	14.1	14.2	13.5	14.6	14.0
13	13.8	14.2	13.8	14.2	14.1	13.7	14.4	13.8
14	14.0	14.2	13.9	14.4	14.1	13.8	14.6	12.9
15	14.2	14.4	14.0	14.5	14.3	13.9	14.7	14.0
16	14.0	14.4	14.0	13.5	14.2	13.8	14.5	14.0

Output Port

Input Port	9	10	11	12	13	14	15	16
1	14.5	14.9	15.2	14.5	14.6	14.7	14.7	14.7
2	14.3	14.7	14.9	14.3	14.3	14.3	14.4	14.4
3	14.7	15.0	15.3	14.7	14.8	14.8	14.9	14.8
4	13.9	14.2	14.5	13.8	13.9	14.0	14.0	14.0
5	13.8	14.2	14.6	14.0	14.0	14.1	14.0	13.2
6	13.8	14.2	13.9	13.9	13.8	13.9	13.9	14.0
7	14.1	13.8	15.0	14.5	14.5	14.6	14.6	14.5
8	14.4	14.8	15.0	14.5	14.5	14.5	13.7	14.5
9	13.9	14.2	14.5	13.9	13.9	13.9	14.0	14.0
10	14.4	14.8	15.0	14.5	14.4	13.2	14.5	14.6
11	14.1	14.5	14.7	13.1	14.1	14.2	14.3	14.2
12	14.0	14.4	13.6	14.0	14.0	14.0	14.2	14.2
13	12.9	14.0	14.4	13.8	13.8	14.0	14.0	13.8
14	14.0	14.4	14.5	13.9	14.0	14.0	14.2	14.2
15	14.1	14.5	14.6	14.1	12.7	14.1	14.3	14.2
16	13.9	14.3	14.5	14.0	14.0	14.1	13.9	14.0

Table 31. Optical Star Coupler #1187074 Loss Data

16 X 16 Optical Coupler Power Losses (dB)

Output Port

Input Port	1	2	3	4	5	6	7	8
1	14.0	14.2	14.8	14.5	14.1	13.8	14.1	14.1
2	14.5	14.9	14.8	14.9	14.3	14.2	14.9	14.9
3	14.5	14.6	14.8	14.1	14.0	14.0	14.6	14.0
4	14.9	14.6	14.8	14.9	14.9	14.2	14.2	14.5
5	14.0	13.9	14.4	14.1	14.0	13.8	13.9	14.0
6	14.5	14.4	14.8	14.9	14.9	14.0	14.4	14.3
7	14.1	14.4	14.8	14.5	14.3	14.4	14.2	14.1
8	14.0	13.9	14.6	13.9	14.0	13.8	13.9	14.0
9	14.9	14.9	14.8	14.9	14.3	14.8	14.9	14.9
10	14.0	14.6	14.8	14.9	14.1	13.8	14.4	14.1
11	14.0	14.2	14.4	14.7	14.0	13.8	13.9	14.0
12	14.0	13.9	14.6	14.7	14.1	13.8	13.9	14.0
13	14.0	14.0	14.8	14.9	14.7	14.6	14.4	14.3
14	14.0	14.1	14.8	13.9	14.0	13.8	13.9	14.0
15	14.0	14.2	14.8	14.5	14.5	14.4	14.2	14.3
16	14.0	13.9	14.6	14.7	14.0	13.8	13.9	14.0

Output Port

Input Port	9	10	11	12	13	14	15	16
1	14.9	14.2	14.8	14.5	14.1	13.8	14.1	14.1
2	14.9	14.7	14.9	13.9	14.3	14.3	14.1	14.7
3	14.9	13.9	14.9	13.9	14.0	13.9	14.0	14.1
4	14.9	14.7	14.9	13.9	14.5	14.9	14.1	14.9
5	14.2	13.9	14.4	13.8	14.0	13.9	14.0	14.0
6	14.9	14.1	14.9	13.9	14.0	13.9	14.1	14.5
7	14.9	14.1	14.9	13.9	14.0	14.1	14.0	14.0
8	14.6	13.9	14.4	13.9	14.0	13.9	14.0	14.0
9	14.9	14.9	14.9	13.9	14.5	14.7	14.3	14.9
10	14.6	13.9	14.9	13.9	14.0	13.9	14.0	14.0
11	14.6	13.9	14.9	13.9	14.0	13.9	14.0	14.0
12	14.9	13.9	14.9	13.9	14.0	13.9	14.0	14.0
13	14.9	14.5	14.9	13.9	14.3	14.5	14.3	14.3
14	14.6	13.9	14.6	13.9	14.0	13.9	14.0	14.0
15	14.9	13.9	14.2	13.9	14.0	14.1	14.0	14.0
16	14.2	13.9	14.6	13.9	14.0	13.9	14.0	14.0

Table 32. Optical Star Coupler #1287185 Loss Data

16 X 16 Optical Coupler Power Losses (dB)

Output Port

Input Port	1	2	3	4	5	6	7	8
1	13.3	13.9	14.8	14.9	14.0	14.0	13.9	14.0
2	13.5	13.4	13.8	14.9	13.6	13.8	13.9	14.0
3	14.0	13.9	14.8	14.9	14.0	14.0	14.1	14.0
4	13.5	13.9	13.8	14.5	13.3	13.8	13.9	14.0
5	14.0	13.9	14.8	14.9	14.0	14.2	14.6	14.5
6	14.0	13.9	14.6	14.9	14.0	13.8	13.9	14.0
7	14.0	13.9	14.8	14.9	14.0	14.0	14.1	14.1
8	14.0	13.9	14.0	14.9	14.0	13.8	13.9	14.0
9	13.8	13.2	14.0	14.9	13.8	13.8	13.9	14.0
10	14.1	13.9	14.8	14.9	14.0	13.8	14.6	14.3
11	14.0	13.9	14.8	14.9	14.0	14.2	14.4	14.1
12	14.5	13.9	14.8	14.9	14.0	14.6	14.4	14.3
13	14.0	13.9	14.8	14.9	14.0	14.0	14.1	14.1
14	14.3	13.9	14.8	14.9	14.0	13.8	14.6	14.7
15	14.0	13.7	14.2	14.9	13.8	13.8	13.9	14.0
16	14.0	13.9	14.2	14.9	14.0	13.8	14.2	14.0

Output Port

Input Port	9	10	11	12	13	14	15	16
1	13.9	13.9	13.9	13.9	14.0	13.9	14.0	14.7
2	13.4	13.8	13.4	13.6	14.0	13.1	13.8	14.0
3	13.9	13.9	14.1	13.9	14.0	13.9	14.0	14.7
4	13.2	13.4	13.9	13.9	13.3	13.3	13.6	14.0
5	13.9	13.9	13.9	13.9	14.0	13.9	14.0	14.7
6	13.9	13.9	14.1	13.9	14.0	13.9	14.0	14.1
7	13.9	13.3	14.1	13.9	14.0	13.9	14.0	14.7
8	13.9	13.9	13.9	13.9	14.0	13.9	14.0	14.0
9	13.7	13.9	13.9	13.9	13.8	13.4	14.0	14.0
10	13.9	13.9	14.4	13.9	14.0	13.9	14.0	14.9
11	13.9	13.9	13.9	13.9	14.0	13.9	14.0	14.5
12	13.9	13.9	14.4	13.9	14.0	13.9	14.0	14.9
13	13.9	13.9	13.9	13.9	14.0	13.9	14.0	14.9
14	13.9	13.9	14.9	14.1	14.0	13.9	14.0	14.9
15	13.9	13.9	13.9	13.9	13.6	13.1	13.8	14.0
16	13.1	13.9	13.9	13.9	14.0	13.6	13.6	14.0

Table 33. Optical Star Coupler #1287191 Loss Data

16 X 16 Optical Coupler Power Losses (dB)

Output Port

Input Port	1	2	3	4	5	6	7	8
1	14.1	14.1	14.5	14.1	14.2	14.5	14.2	14.2
2	14.5	14.2	14.3	14.3	14.3	14.5	14.3	14.4
3	14.5	14.7	14.7	14.2	14.3	14.6	14.4	14.5
4	13.9	14.4	14.3	14.0	14.1	14.3	14.0	14.1
5	14.1	14.2	14.2	13.9	13.9	14.1	13.8	14.0
6	14.0	14.2	14.2	13.8	13.9	14.1	13.9	14.0
7	14.0	13.9	14.2	13.8	13.9	14.2	13.8	13.9
8	14.3	14.6	14.5	14.2	14.2	14.3	14.2	14.4
9	15.0	15.3	15.2	14.5	14.8	15.2	14.9	15.0
10	15.3	15.7	15.5	15.1	15.2	15.5	15.2	15.3
11	14.1	14.0	14.3	13.9	13.9	14.3	13.9	13.8
12	14.6	14.8	14.7	14.3	14.4	14.7	13.8	14.5
13	14.4	14.7	14.6	14.1	13.9	14.5	14.2	14.4
14	14.3	14.6	14.4	14.1	14.2	14.4	14.2	14.3
15	14.1	14.4	14.3	13.9	14.0	14.3	14.0	14.1
16	14.3	14.5	14.4	14.1	14.1	14.5	14.1	14.2

Output Port

Input Port	9	10	11	12	13	14	15	16
1	14.5	14.4	14.4	14.0	14.2	14.2	14.2	15.2
2	14.6	14.4	14.5	14.3	14.4	14.5	14.4	15.2
3	14.6	14.5	14.6	14.3	14.1	14.5	14.4	15.3
4	14.3	14.1	14.2	13.9	14.1	13.9	14.0	15.0
5	14.1	14.0	14.0	13.8	14.0	14.0	13.8	14.9
6	14.2	14.0	14.1	13.4	14.0	14.0	13.9	14.9
7	14.1	14.0	14.1	13.7	13.9	14.0	13.8	14.8
8	14.5	14.3	14.5	14.1	14.3	14.3	14.3	15.0
9	15.1	15.0	15.1	14.8	14.8	15.0	14.9	15.8
10	15.3	15.3	14.4	15.2	15.2	15.3	15.2	16.2
11	14.2	14.1	14.2	13.8	14.0	14.1	14.0	15.0
12	14.6	14.5	14.6	14.3	14.4	14.5	14.3	15.4
13	14.4	14.4	14.4	14.2	14.1	14.4	14.2	15.2
14	14.4	14.2	14.4	14.1	14.3	14.3	14.2	15.0
15	14.3	13.9	14.2	13.9	14.0	14.1	14.1	15.0
16	14.3	14.2	14.3	14.0	14.1	14.2	13.8	15.1

Table 34. Optical Star Coupler #1187081 Loss Data

16 X 16 Optical Coupler Power Losses (dB)

Input Port	Output Port 1	2	3	4	5	6	7	8
1	14.0	14.4	14.3	14.7	14.4	14.2	14.5	14.6
2	14.4	14.1	14.3	14.6	14.4	14.3	14.2	14.6
3	14.4	14.4	14.3	14.6	14.4	14.3	14.5	14.6
4	14.3	14.3	13.8	14.5	14.1	13.9	14.4	14.5
5	14.5	14.5	14.3	14.6	14.5	14.3	14.5	14.2
6	14.2	14.2	14.0	14.4	14.2	14.0	14.2	14.3
7	14.3	14.3	14.0	14.6	14.0	14.1	14.4	14.6
8	14.3	14.3	13.9	14.5	14.2	13.9	14.3	14.5
9	14.7	14.7	14.5	14.9	14.7	14.5	14.8	14.8
10	14.3	14.3	14.1	14.4	14.2	14.1	14.3	14.4
11	14.8	14.7	14.6	15.0	14.7	14.6	14.8	15.0
12	14.8	14.7	14.6	14.8	14.7	14.6	14.8	14.8
13	14.5	14.4	14.4	14.7	14.5	14.4	14.5	14.7
14	14.6	14.6	14.5	14.9	14.7	14.5	14.7	14.7
15	14.5	14.2	14.4	14.8	14.5	14.3	14.3	14.7
16	14.6	14.6	14.5	14.5	14.6	14.4	14.7	14.7

Input Port	Output Port 9	10	11	12	13	14	15	16
1	14.1	14.5	14.6	14.6	14.6	14.5	14.4	14.6
2	14.3	14.6	14.6	14.5	14.6	14.5	14.4	14.6
3	14.3	14.6	14.6	14.5	13.8	14.5	14.4	14.4
4	14.2	14.4	14.5	14.4	14.4	14.4	14.2	14.4
5	14.4	14.5	14.6	14.6	14.6	14.5	14.4	14.7
6	14.1	14.3	14.4	14.3	14.4	14.3	13.8	14.4
7	14.3	14.5	14.6	14.5	14.5	14.4	14.3	14.5
8	14.2	14.4	14.5	14.4	14.4	14.3	14.3	14.4
9	14.6	14.3	14.9	14.8	14.9	14.7	14.5	14.9
10	14.2	14.3	14.4	14.4	14.4	14.0	14.2	14.4
11	14.6	14.9	15.0	14.9	14.8	14.8	14.8	14.2
12	14.7	14.9	14.5	14.8	14.9	14.8	14.7	14.9
13	14.5	14.7	14.7	14.2	14.7	14.6	14.5	14.7
14	13.8	14.4	14.5	14.4	14.4	14.4	14.3	14.4
15	14.4	14.7	14.7	14.5	14.7	14.6	14.5	14.7
16	14.6	14.7	14.7	14.7	14.8	14.6	14.6	14.8

Table 35. Optical Star Coupler #1187075 Loss Data

16 X 16 Optical Coupler Power Losses (dB)

Output Port

Input Port	1	2	3	4	5	6	7	8
1	13.6	13.7	13.8	13.7	13.7	13.6	13.8	13.8
2	13.9	13.7	13.8	13.8	13.8	13.7	13.8	13.8
3	14.3	13.9	14.2	14.0	13.2	13.9	14.1	14.0
4	13.9	13.4	14.0	13.5	13.5	13.3	13.6	12.4
5	13.6	13.6	14.0	13.6	13.6	13.5	13.7	13.6
6	14.1	13.7	14.1	13.8	13.8	13.6	13.5	13.8
7	14.5	14.2	13.8	14.2	14.2	14.1	14.2	14.2
8	14.2	13.6	14.3	13.8	13.8	13.5	13.9	13.8
9	14.4	14.0	14.4	14.0	14.0	13.9	14.2	14.0
10	14.7	13.9	14.7	14.2	14.2	13.6	14.6	14.2
11	14.5	13.8	14.6	14.0	14.1	13.8	14.5	14.0
12	14.3	13.9	14.4	13.6	13.9	13.8	14.2	13.9
13	14.4	13.6	14.5	14.0	14.0	13.4	14.4	14.0
14	14.7	14.2	14.7	14.2	14.2	14.1	14.0	14.
15	13.9	13.5	14.0	13.6	13.5	13.4	13.9	13.6
16	14.8	14.3	14.8	13.7	14.4	14.2	14.7	14.3

Output Port

Input Port	9	10	11	12	13	14	15	16
1	13.4	13.8	13.9	13.8	13.7	13.8	13.7	13.7
2	13.7	13.8	14.0	13.8	13.8	13.6	13.7	13.8
3	14.1	14.0	14.1	13.9	14.0	14.3	14.0	14.0
4	13.6	13.6	13.8	13.5	13.5	13.8	13.6	13.4
5	13.2	13.7	13.8	13.6	13.6	13.7	13.5	13.6
6	13.8	13.8	14.0	13.8	13.3	14.1	13.7	13.8
7	14.2	14.2	14.5	14.3	14.2	14.4	14.1	14.2
8	13.9	13.8	14.0	13.1	13.0	14.1	13.8	13.6
9	14.0	14.1	14.3	14.1	13.8	14.3	13.4	14.0
10	14.3	14.3	14.5	14.2	14.2	14.6	14.3	13.8
11	14.1	14.1	14.3	14.0	14.0	14.3	14.1	13.4
12	14.0	13.3	14.2	13.9	13.8	14.2	13.9	13.9
13	14.1	14.1	14.2	13.9	14.0	14.4	14.1	13.7
14	14.3	14.2	14.5	14.3	13.8	14.6	14.1	14.2
15	13.6	13.6	13.0	13.5	13.5	13.8	13.6	13.5
16	14.4	14.1	14.6	14.4	14.3	14.7	14.4	14.3

Table 36. Optical Star Coupler #1187076 Loss Data

16 X 16 Optical Coupler Power Losses (dB)

Output Port

Input Port	1	2	3	4	5	6	7	8
1	15.9	15.3	16.0	15.6	16.0	15.3	15.8	15.3
2	16.2	15.4	16.0	15.8	15.5	15.5	15.6	15.7
3	16.3	15.7	16.2	16.0	15.8	15.9	15.8	15.8
4	16.2	15.5	16.0	15.8	15.4	15.7	15.6	15.6
5	16.3	15.6	16.0	15.8	15.6	15.8	15.7	15.7
6	15.8	15.2	16.0	15.6	15.7	15.3	15.5	15.2
7	15.7	15.2	16.0	15.6	15.7	15.3	15.5	15.2
8	16.2	15.5	16.3	15.9	16.2	15.6	15.7	15.5
9	16.3	15.6	16.4	15.9	16.3	15.5	15.9	15.6
10	15.8	15.2	15.9	15.3	15.8	15.1	15.4	15.1
11	16.7	15.9	16.7	16.2	16.5	15.9	16.2	15.9
12	16.0	15.2	16.0	15.7	15.9	15.3	15.4	15.2
13	16.5	15.8	16.5	16.0	16.4	15.8	16.0	15.8
14	16.0	15.2	16.0	15.7	16.0	15.2	15.6	15.1
15	16.0	15.3	15.9	15.6	15.9	15.1	15.5	15.2
16	16.1	15.4	16.2	15.9	16.1	15.3	15.7	15.4

Output Port

Input Port	9	10	11	12	13	14	15	16
1	16.0	15.4	15.9	15.6	15.4	15.5	15.5	15.5
2	16.2	15.4	16.0	15.8	15.5	15.5	15.6	15.7
3	16.3	15.7	16.2	16.0	15.8	15.9	15.8	15.8
4	16.2	15.5	16.0	15.8	15.4	15.7	15.6	15.6
5	16.3	15.6	16.0	15.8	15.6	15.8	15.7	15.7
6	15.9	15.3	15.8	15.6	15.3	15.5	15.4	15.4
7	16.0	15.3	15.8	15.6	15.4	15.4	15.4	15.4
8	16.0	15.6	16.1	15.9	15.6	15.8	15.7	15.7
9	16.3	15.3	16.2	15.9	15.7	15.8	15.7	15.8
10	15.8	15.2	15.5	15.4	15.3	15.4	15.3	15.3
11	16.6	15.9	16.6	16.2	16.0	16.1	15.8	16.0
12	15.9	15.3	16.0	15.6	15.4	15.5	15.5	15.4
13	16.4	15.8	16.1	16.0	15.9	16.0	15.9	15.9
14	15.9	15.3	15.9	15.6	15.4	15.5	15.5	15.5
15	16.0	15.2	15.8	15.6	15.2	15.5	15.4	15.4
16	16.1	15.4	16.0	15.7	15.5	15.7	15.5	15.2

Table 37. Optical Star Coupler #1288188 Loss Data

16 X 16 Optical Coupler Power Losses (dB)

Output Port

Input Port	1	2	3	4	5	6	7	8
1	14.0	13.9	13.8	13.9	14.0	13.8	13.9	13.2
2	13.5	13.1	13.0	13.4	13.5	13.0	13.2	13.2
3	13.2	13.1	12.4	13.1	13.2	13.0	13.1	13.2
4	14.0	13.9	13.8	13.9	14.0	13.6	13.9	14.0
5	14.0	13.9	13.8	13.9	14.0	13.8	13.9	14.0
6	13.3	13.9	13.8	12.7	14.0	13.0	13.4	13.6
7	13.2	13.7	13.0	13.6	13.6	13.0	13.1	13.2
8	14.0	13.9	13.8	13.9	14.0	13.5	13.9	14.0
9	13.2	13.4	13.0	13.1	13.5	13.0	13.1	13.2
10	13.2	13.2	13.0	13.1	13.6	13.0	13.1	13.2
11	13.3	13.2	13.0	13.9	13.0	13.0	13.1	13.2
12	12.5	13.9	13.8	13.6	14.0	13.2	13.5	13.3
13	13.2	13.5	13.0	13.1	13.5	13.0	12.4	13.2
14	13.3	13.7	13.7	13.9	14.0	13.0	13.9	13.3
15	14.0	13.9	13.8	13.9	14.0	12.5	13.9	14.0
16	13.2	13.2	13.0	13.9	13.3	13.0	13.5	13.2

Output Port

Input Port	9	10	11	12	13	14	15	16
1	13.9	13.9	13.9	13.9	14.0	13.9	14.0	14.0
2	13.1	13.6	13.4	13.1	13.2	13.8	13.2	13.2
3	13.1	13.3	13.2	13.1	13.2	13.1	13.2	13.2
4	13.9	13.9	13.9	13.9	12.6	13.9	14.0	14.0
5	13.9	13.9	13.1	13.9	14.0	13.9	14.0	14.0
6	13.1	13.8	13.9	13.6	13.3	13.8	13.3	14.0
7	11.8	13.4	13.5	13.1	13.2	13.4	13.2	13.3
8	13.9	13.9	13.9	13.9	14.0	13.1	14.0	14.0
9	13.1	13.3	13.2	13.1	13.2	13.3	12.5	13.2
10	13.1	13.1	13.1	13.1	13.2	13.3	13.2	13.2
11	13.1	13.8	13.7	13.3	13.2	13.8	13.3	13.6
12	13.7	13.9	13.9	13.4	13.2	13.9	13.3	14.0
13	13.1	13.4	13.7	13.1	13.2	13.4	13.2	13.5
14	13.5	13.9	13.9	12.5	13.2	13.8	13.3	13.6
15	13.9	13.9	13.9	13.9	13.6	13.9	14.0	14.0
16	13.1	13.1	13.5	13.1	13.2	13.4	13.2	12.9

Table 38. Optical Star Coupler #0787138 Loss Data

16 X 16 Optical Coupler Power Losses (dB)

Output Port

Input Port	1	2	3	4	5	6	7	8
1	14.0	13.9	13.8	13.9	14.0	13.8	13.9	14.0
2	14.0	14.4	13.8	13.9	14.0	14.4	13.9	14.0
3	14.0	13.9	13.8	14.3	14.0	14.0	13.9	14.0
4	14.0	14.1	13.8	13.9	14.0	14.0	14.1	14.0
5	14.0	13.9	13.8	13.9	14.0	13.8	13.9	14.0
6	14.0	13.9	13.8	13.9	14.0	13.8	13.9	14.0
7	14.5	14.2	14.2	14.3	14.7	14.4	14.2	14.0
8	14.0	13.9	13.8	13.9	14.0	13.8	13.9	14.0
9	14.0	13.9	13.8	13.9	14.0	13.8	13.9	14.0
10	14.1	14.6	14.0	14.3	14.3	14.6	14.1	14.1
11	14.0	13.9	13.8	13.9	14.0	13.8	13.9	14.0
12	14.0	13.9	13.8	13.9	14.0	13.8	13.9	14.0
13	14.0	13.9	13.8	13.9	14.0	13.8	13.9	14.0
14	14.7	14.6	14.0	14.3	14.0	14.4	14.2	14.1
15	14.0	13.9	13.8	13.9	14.0	13.8	13.9	14.0
16	14.0	13.9	13.8	13.9	14.0	13.8	13.9	14.0

Output Port

Input Port	9	19	11	12	13	14	15	16
1	13.9	13.9	13.9	13.9	14.0	13.9	14.0	14.0
2	14.1	13.9	14.4	13.9	14.0	13.9	14.0	14.0
3	13.9	14.1	14.4	13.9	14.0	13.9	14.0	14.0
4	14.1	14.1	14.4	13.9	14.0	14.3	14.0	14.0
5	13.9	13.9	13.9	13.9	14.0	13.9	14.0	14.0
6	13.9	13.9	13.9	13.9	14.0	13.9	14.0	14.0
7	14.6	13.9	14.9	14.3	14.3	14.3	14.5	14.5
8	13.9	13.9	14.1	13.9	14.0	13.9	14.0	14.0
9	13.9	13.9	13.9	13.9	14.0	13.9	14.0	14.0
10	14.1	14.1	14.6	13.9	14.0	13.9	14.7	14.0
11	13.9	13.9	14.4	13.9	14.0	13.8	14.0	14.0
12	13.9	13.9	13.9	13.9	14.0	13.9	14.0	14.0
13	13.9	13.9	13.9	13.9	14.0	13.9	14.0	14.0
14	14.6	14.7	14.9	14.7	14.1	14.1	14.3	14.0
15	13.9	13.9	13.9	13.9	14.0	14.1	14.0	14.0
16	13.9	13.9	13.9	13.9	14.0	13.9	14.0	14.0

Table 39. Optical Star Coupler #1187055 Loss Data

16 X 16 Optical Coupler Power Losses (dB)

Output Port

Input Port	1	2	3	4	5	6	7	8
1	14.0	14.4	14.4	14.5	14.5	14.1	14.6	14.6
2	14.6	14.4	14.3	14.4	14.4	14.4	13.3	14.5
3	14.7	14.4	12.9	14.1	14.4	14.4	14.7	14.4
4	15.2	14.9	14.8	14.9	15.0	14.9	15.0	14.9
5	15.5	14.6	15.1	15.5	14.1	15.1	15.4	15.3
6	14.9	14.6	14.5	14.9	14.6	14.6	14.7	14.7
7	14.8	14.4	14.3	14.8	14.5	14.4	14.7	14.6
8	15.1	14.8	14.4	13.7	14.8	14.8	15.1	14.8
9	15.2	14.9	14.7	15.1	14.9	14.9	15.1	14.7
10	15.0	13.7	14.6	15.0	14.3	14.6	15.0	14.8
11	14.5	14.2	14.1	14.5	14.3	14.3	14.1	14.3
12	14.4	14.3	14.3	14.7	14.4	13.5	14.7	14.5
13	14.7	14.3	14.0	14.1	14.4	14.3	14.6	14.4
14	15.3	15.0	14.7	15.2	15.0	14.9	15.2	12.7
15	14.4	14.3	14.3	14.8	14.4	13.9	14.7	14.6
16	14.8	14.4	14.2	14.6	14.5	14.4	14.7	14.5

Output Port

Input Port	9	10	11	12	13	14	15	16
1	14.5	14.6	14.9	14.5	14.5	14.5	14.9	14.7
2	14.0	14.4	14.6	14.4	14.4	14.5	15.2	14.4
3	14.4	14.4	14.7	14.2	14.4	14.4	15.2	14.6
4	14.7	14.9	13.7	14.9	15.0	15.0	15.8	14.9
5	15.2	15.3	15.6	15.2	15.2	15.3	15.8	15.4
6	14.5	14.6	14.7	14.6	14.6	14.7	15.3	13.2
7	14.5	14.5	14.8	14.5	13.0	14.5	15.1	14.6
8	14.8	14.8	15.1	14.3	14.9	14.7	15.5	15.0
9	14.9	13.5	15.1	14.8	14.9	14.9	15.6	15.0
10	14.8	14.8	15.1	14.7	14.7	14.7	15.3	14.9
11	12.9	14.3	14.3	14.3	14.3	14.3	15.0	14.3
12	14.5	14.5	14.8	14.4	14.4	14.5	14.5	14.6
13	14.4	14.3	14.7	13.2	14.4	14.2	15.0	14.5
14	15.0	14.7	15.2	14.9	15.0	15.0	15.6	15.1
15	14.5	14.5	14.9	14.5	14.4	14.5	13.7	14.6
16	14.5	14.5	14.8	14.3	14.4	13.2	15.0	14.6

Table 40. Optical Star Coupler #0987002 Loss Data

16 X 16 Optical Coupler Power Losses (dB)

Output Port

Input Port	1	2	3	4	5	6	7	8
1	13.8	14.6	14.9	14.3	14.5	14.4	14.3	14.4
2	14.7	14.9	15.3	14.7	14.9	14.7	14.7	14.7
3	14.3	14.4	14.6	14.1	14.4	14.3	14.3	14.3
4	14.4	14.6	14.6	14.4	14.5	14.4	14.2	14.5
5	14.3	14.5	14.4	14.3	14.4	14.3	14.3	14.2
6	14.2	14.3	14.3	14.1	14.2	14.1	14.1	14.2
7	14.5	14.7	14.6	14.4	14.6	14.4	14.4	14.5
8	14.4	14.6	14.5	14.4	14.5	14.1	14.4	14.1
9	14.7	14.9	14.7	14.6	14.8	14.6	14.7	14.4
10	14.2	14.2	14.4	14.0	14.3	14.2	14.2	14.3
11	14.9	14.7	15.1	14.7	14.8	14.8	14.8	14.9
12	14.3	14.5	14.3	14.2	14.4	13.8	14.2	14.1
13	15.0	15.1	15.2	14.6	15.1	15.0	15.0	15.0
14	14.2	14.5	14.5	14.2	14.4	14.3	14.2	14.3
15	14.7	14.9	14.9	14.7	14.8	14.7	14.4	14.7
16	15.5	15.7	15.7	15.5	15.6	15.5	15.3	15.5

Output Port

Input Port	9	10	11	12	13	14	15	16
1	14.4	14.4	14.9	14.5	14.3	14.4	14.2	14.5
2	14.8	14.8	15.2	14.8	14.6	14.6	14.6	14.9
3	14.4	14.2	14.8	14.5	14.3	14.3	14.2	14.2
4	14.4	14.5	14.8	14.5	14.1	14.5	14.3	14.5
5	13.9	14.3	14.8	14.5	14.2	14.4	14.2	14.4
6	14.2	14.1	14.7	14.4	14.1	14.2	14.0	14.2
7	14.5	14.5	14.9	14.6	14.4	14.5	14.1	14.5
8	14.4	14.4	14.9	14.5	14.3	14.5	14.3	14.5
9	14.6	14.7	15.2	14.8	14.6	14.7	14.5	14.8
10	14.3	14.2	14.8	14.4	14.2	14.2	14.1	14.1
11	14.9	14.8	15.3	15.0	14.7	14.8	14.7	14.8
12	14.3	14.3	14.8	14.4	14.2	14.4	14.2	14.4
13	15.0	14.9	15.5	15.1	14.9	15.1	14.8	15.0
14	14.3	14.3	14.7	14.2	14.2	14.2	14.2	14.3
15	14.7	14.7	15.0	14.8	14.4	14.8	14.6	14.8
16	15.6	15.5	15.7	15.6	15.3	15.6	15.4	15.6

Table 41. Optical Star Coupler #1187079 Loss Data

16 X 16 Optical Coupler Power Losses (dB)

Output Port

Input Port	1	2	3	4	5	6	7	8
1	16.2	15.7	16.2	15.6	16.7	15.7	16.2	16.4
2	16.1	16.3	16.4	15.7	16.3	16.2	16.3	16.5
3	15.5	15.6	15.6	14.8	15.9	15.4	15.4	15.7
4	16.0	16.1	16.1	15.4	16.4	15.9	15.9	16.1
5	15.7	15.7	15.7	15.1	16.0	15.6	15.6	15.9
6	15.7	15.9	16.0	15.3	15.9	16.0	15.9	16.1
7	15.5	15.5	15.0	14.7	15.8	15.3	15.4	15.7
8	16.0	16.0	15.9	15.3	16.3	15.7	15.8	16.1
9	16.1	16.1	16.1	15.4	16.4	16.0	16.0	16.2
10	15.6	15.5	15.5	14.9	15.8	15.4	15.4	15.7
11	15.9	15.6	15.6	15.1	16.1	15.7	15.7	15.7
12	16.0	15.8	15.9	15.4	16.0	15.9	15.9	16.2
13	15.7	15.5	15.4	14.8	15.9	15.5	15.5	15.7
14	16.0	15.7	15.8	15.2	16.2	15.8	15.8	15.3
15	16.0	15.7	15.7	15.2	16.1	15.8	15.1	16.0
16	15.8	15.5	15.6	15.0	16.0	15.6	15.6	15.4

Output Port

Input Port	9	10	11	12	13	14	15	16
1	16.0	15.6	16.0	15.8	15.7	15.7	16.1	15.7
2	16.1	15.8	16.0	15.9	15.7	15.9	16.2	15.8
3	15.2	14.9	15.2	15.0	14.1	15.0	14.9	14.8
4	15.7	15.5	15.8	15.4	15.4	15.6	15.8	14.5
5	15.5	14.5	15.4	15.2	15.0	15.1	15.4	15.1
6	15.7	15.4	15.7	15.5	15.4	15.5	15.8	15.4
7	15.3	14.9	15.2	15.0	14.9	15.0	15.3	15.0
8	15.7	15.2	15.6	15.5	15.3	15.0	15.7	15.3
9	15.8	15.5	15.0	15.6	15.5	15.6	15.9	15.5
10	15.3	14.9	15.2	15.0	14.5	15.0	14.5	14.8
11	14.7	15.2	15.5	15.1	15.1	15.4	15.6	15.1
12	15.8	15.5	15.5	15.6	15.4	15.6	15.8	15.4
13	15.4	15.0	15.1	15.1	15.0	15.2	15.4	15.0
14	15.5	15.3	15.4	14.8	15.3	15.5	15.7	15.2
15	15.6	15.3	15.3	15.4	15.2	15.4	15.6	15.2
16	15.2	15.1	15.2	14.4	15.1	15.3	15.5	15.0

Table 42. Optical Star Coupler #1287186 Loss Data

16 X 16 Optical Coupler Power Losses (dB)

Output Port

Input Port	1	2	3	4	5	6	7	8
1	14.3	14.7	14.4	14.7	14.7	14.5	14.5	14.4
2	14.8	14.7	14.5	14.8	14.7	14.0	14.7	14.5
3	15.1	15.2	14.9	14.8	14.9	14.9	14.9	14.9
4	15.1	15.1	14.8	14.9	14.5	14.8	14.8	14.9
5	15.0	15.2	14.9	15.1	15.1	15.0	14.7	14.9
6	14.9	15.0	14.3	15.2	14.9	14.8	14.8	14.6
7	14.4	14.4	14.1	14.7	14.4	14.2	14.3	14.1
8	14.9	14.8	14.6	15.2	14.9	14.7	14.8	14.6
9	14.9	15.0	14.6	15.1	14.8	14.7	14.6	14.9
10	15.5	14.8	15.1	15.4	15.3	15.2	15.2	15.4
11	15.5	15.3	15.1	15.4	15.4	15.3	15.2	15.4
12	15.5	15.3	15.0	15.5	15.6	15.2	15.2	15.2
13	15.2	15.0	14.5	15.2	15.2	14.9	14.9	15.1
14	15.1	15.0	14.7	15.2	15.2	14.9	14.8	15.1
15	15.9	15.6	15.4	15.8	15.9	15.5	15.5	15.7
16	15.0	14.7	14.6	14.9	14.9	14.4	14.6	14.9

Output Port

Input Port	9	10	11	12	13	14	15	16
1	14.5	14.4	14.3	14.4	14.4	14.6	13.8	14.8
2	14.7	14.6	14.3	14.5	14.1	14.6	13.8	14.9
3	14.9	14.9	14.7	14.9	14.7	15.0	14.2	15.3
4	15.0	14.9	14.6	14.8	14.6	15.0	14.2	15.2
5	14.9	14.9	14.7	14.9	14.8	15.0	14.2	15.3
6	14.8	14.7	14.5	14.4	14.6	14.8	14.0	15.0
7	14.3	14.2	13.9	[illegible]	14.0	14.3	12.7	14.5
8	14.8	14.7	13.9	14.6	14.5	14.7	13.9	15.0
9	14.4	14.6	14.5	14.6	14.5	14.8	14.0	15.1
10	15.4	15.2	14.8	15.1	15.0	15.2	14.5	15.5
11	15.4	15.2	15.1	15.1	15.0	14.8	14.5	15.3
12	15.3	15.1	15.1	14.9	15.0	15.1	14.4	15.2
13	15.0	14.8	14.8	14.5	14.7	14.9	14.1	15.2
14	15.0	14.5	14.8	14.7	14.7	14.9	14.1	15.1
15	15.7	15.5	15.4	15.4	15.3	15.5	14.8	15.7
16	14.8	14.6	14.6	14.6	13.7	14.7	13.9	15.0

Table 43. Optical Star Coupler #1287189 Loss Data

16 X 16 Optical Coupler Power Losses (dB)

Output Port

Input Port	1	2	3	4	5	6	7	8
1	13.5	13.6	13.6	14.3	13.7	13.6	13.8	13.8
2	14.1	13.8	12.7	14.2	13.6	13.6	13.8	13.8
3	14.0	13.6	13.5	14.2	13.6	13.5	13.7	13.7
4	14.0	13.6	13.4	14.1	13.5	13.5	13.7	13.7
5	14.1	13.7	13.5	14.2	13.5	13.4	13.7	13.8
6	14.0	13.6	13.4	13.9	13.5	13.5	13.6	13.8
7	14.2	13.8	13.6	14.3	13.6	12.5	13.8	14.0
8	14.5	14.1	14.0	14.7	14.1	14.0	14.2	13.6
9	14.4	14.0	13.8	14.5	13.1	13.7	14.0	14.1
10	14.2	13.8	13.6	14.4	13.8	13.6	12.7	13.9
11	14.2	13.8	13.7	14.4	13.7	13.6	13.8	13.9
12	16.3	15.0	15.9	16.6	16.1	16.0	16.1	16.1
13	14.0	13.6	13.5	14.1	13.5	13.4	13.6	13.8
14	13.9	13.5	13.4	14.1	13.4	13.4	13.6	13.6
15	14.1	13.7	13.5	13.5	13.6	13.5	13.7	13.8
16	14.1	13.8	13.6	14.3	13.5	13.5	13.8	14.0

Output Port

Input Port	9	10	11	12	13	14	15	16
1	13.6	13.5	13.8	13.8	13.9	13.9	13.9	13.9
2	13.6	13.4	13.7	13.7	13.9	13.9	13.9	13.9
3	13.5	13.4	13.6	13.6	13.3	13.8	13.4	13.6
4	13.5	13.4	13.6	13.5	13.5	13.8	12.9	13.8
5	12.8	13.3	13.6	13.2	13.7	13.7	13.7	13.8
6	13.5	12.9	13.6	13.6	13.8	13.8	13.7	13.8
7	13.6	13.6	13.7	13.7	13.9	13.8	13.8	14.0
8	14.0	13.9	14.1	14.1	14.1	14.3	14.2	14.2
9	13.8	13.8	13.8	13.9	14.1	14.1	14.1	14.2
10	13.7	13.5	13.8	13.8	13.9	13.9	13.9	14.0
11	13.2	13.5	13.6	12.8	13.8	13.8	13.7	13.8
12	16.0	15.8	16.2	16.1	16.1	16.2	16.2	16.2
13	13.4	13.3	13.6	13.6	13.7	12.6	13.6	13.8
14	13.4	13.3	13.6	13.5	13.5	13.7	13.5	13.0
15	13.6	13.2	13.8	13.7	13.8	13.8	13.8	13.9
16	13.6	13.5	12.9	13.8	13.9	14.0	13.9	14.0

Table 44. Optical Star Coupler #1187080 Loss Data

16 X 16 Optical Coupler Power Losses (dB)

Output Port

Input Port	1	2	3	4	5	6	7	8
1	14.7	15.3	15.5	15.0	15.0	14.9	15.4	15.5
2	15.0	15.2	15.5	14.6	15.0	15.0	15.1	15.5
3	14.9	15.2	15.4	14.9	14.9	14.1	15.3	15.4
4	15.1	15.3	15.6	15.0	15.1	15.0	15.4	15.5
5	14.8	15.0	15.2	14.7	14.8	14.7	15.1	15.3
6	14.7	14.9	15.2	14.6	14.7	14.6	15.1	15.1
7	14.7	14.9	15.2	14.5	14.7	14.7	14.8	15.2
8	15.6	15.5	14.4	15.5	15.5	15.4	15.9	16.0
9	14.9	15.1	15.4	14.8	14.9	14.9	15.3	15.4
10	14.9	15.1	15.3	14.8	14.3	14.9	15.2	14.7
11	14.7	15.2	15.4	14.9	14.9	14.8	15.3	15.3
12	14.9	14.1	15.1	14.7	14.8	14.7	15.2	15.2
13	14.6	14.8	15.1	13.5	14.6	14.5	14.5	15.0
14	14.7	14.9	15.2	14.6	14.7	14.6	15.0	15.1
15	14.7	14.8	15.2	14.3	14.7	14.6	13.7	15.1
16	15.0	15.1	15.5	14.9	14.3	14.9	15.3	14.6

Output Port

Input Port	9	10	11	12	13	14	15	16
1	14.9	15.0	15.2	15.0	15.5	15.2	15.1	16.0
2	14.9	15.2	15.2	14.7	15.5	14.2	15.1	15.9
3	14.8	15.0	15.1	14.9	15.4	15.1	15.0	15.8
4	15.0	15.2	15.1	15.0	15.5	15.2	15.1	14.8
5	14.6	14.9	14.5	14.7	15.2	14.9	14.8	15.6
6	14.5	14.8	14.8	14.6	15.1	14.9	14.8	15.6
7	14.6	14.9	14.8	13.6	15.2	14.7	14.7	15.6
8	15.5	15.7	15.7	15.4	16.0	15.7	15.6	16.5
9	14.8	15.0	15.0	14.8	15.0	15.0	14.1	15.8
10	14.8	15.1	15.1	14.8	15.4	15.0	15.0	15.8
11	14.8	14.9	15.1	14.9	15.4	15.1	15.0	15.8
12	14.8	15.0	15.0	14.8	15.3	15.0	14.9	15.8
13	14.5	14.8	14.7	14.4	15.1	14.4	14.7	15.5
14	14.6	14.8	14.7	14.5	14.4	14.8	14.3	15.5
15	14.6	14.8	14.8	14.5	15.1	14.5	14.7	15.6
16	14.9	15.2	15.2	14.9	15.5	15.2	15.1	15.9

Table 45. Optical Star Coupler #1287192 Loss Data

16 X 16 Optical Coupler Power Losses (dB)

Input Port	Output Port 1	2	3	4	5	6	7	8
1	14.8	14.8	14.6	15.0	14.7	14.3	14.8	14.6
2	14.2	14.3	14.0	14.4	14.2	14.1	13.8	14.2
3	14.7	14.7	14.5	14.9	14.6	14.4	14.7	14.5
4	14.7	14.8	14.5	14.7	14.7	14.6	14.6	14.6
5	14.4	14.3	14.2	14.6	14.0	14.3	14.4	14.2
6	14.6	14.1	14.3	14.8	14.3	14.4	14.5	14.3
7	14.8	14.9	14.6	15.0	14.8	14.7	14.1	14.8
8	14.1	14.4	13.1	14.4	14.2	14.2	14.3	14.2
9	15.0	15.1	14.8	14.9	15.0	14.9	15.0	15.0
10	14.1	14.2	13.8	14.2	14.1	14.0	14.1	14.0
11	14.7	14.8	14.5	14.9	14.7	14.6	14.7	14.7
12	14.6	14.7	14.5	14.9	14.5	14.5	14.7	14.1
13	15.0	15.1	14.8	14.3	14.9	14.9	14.9	14.9
14	14.5	14.7	14.3	14.5	14.5	14.5	14.5	14.5
15	13.5	14.4	14.0	14.5	14.3	14.2	14.3	14.3
16	14.7	14.7	14.5	14.9	14.6	14.6	14.6	14.6

Input Port	Output Port 9	10	11	12	13	14	15	16
1	15.0	14.8	14.9	14.8	14.6	14.9	15.0	14.6
2	13.9	14.2	14.6	14.1	14.0	14.3	14.4	14.0
3	15.0	14.7	14.6	14.7	14.6	14.9	15.0	14.5
4	14.8	14.6	15.1	14.0	14.4	14.7	14.9	14.3
5	14.6	14.4	14.7	14.4	14.3	14.6	14.6	14.2
6	14.8	14.6	14.9	14.5	14.4	14.7	14.8	14.4
7	14.7	14.8	15.2	14.7	14.6	14.9	14.9	14.6
8	14.4	14.2	14.7	14.2	14.0	14.4	14.5	4.1
9	15.1	14.9	15.4	14.8	14.8	15.0	15.2	14.2
10	14.2	13.6	14.6	13.9	13.5	14.2	14.3	13.8
11	14.8	14.0	15.2	14.6	14.1	14.8	14.9	14.5
12	14.9	14.7	15.0	14.7	14.5	14.9	14.9	14.5
13	15.1	14.9	15.5	14.7	14.7	14.9	15.2	14.3
14	14.7	14.5	15.1	14.3	14.4	14.1	14.7	14.2
15	14.4	14.3	14.8	14.3	14.1	14.4	14.5	14.1
16	14.8	14.7	15.2	14.6	14.5	14.8	14.3	14.4

Table 46. Optical Star Coupler #1287187 Loss Data

D.3.2 Input-to-Input Port Loss Data

Coupler ID#	Minimum Average Crosstalk Loss (dB) Input Port #							
	1	2	3	4	5	6	7	8
1187054	29.3	28.5	28.2	28.6	27.8	27.8	28.2	28.1
1187078	27.4	27.5	27.6	28.1	27.3	27.9	27.8	27.9
1187072	27.5	27.6	27.6	27.6	27.5	27.5	27.7	27.4
1187074	27.8	28.0	28.0	28.0	28.0	28.0	28.0	28.2
1287191	27.3	27.4	27.3	27.5	26.9	27.9	27.8	27.7
0987002	27.8	28.6	28.3	28.6	28.4	28.8	27.7	28.7
1187055	28.2	27.3	26.9	26.7	26.9	27.0	27.1	26.9
1287185	27.6	27.9	27.4	27.6	27.7	27.7	27.5	28.0
1187081	27.9	27.8	28.2	27.5	27.4	27.9	27.2	27.6
1187079	28.2	28.1	28.0	27.9	27.9	28.1	28.0	27.8
1287186	26.5	26.4	26.4	26.5	26.6	26.7	26.5	27.2
1187080	27.8	27.1	27.1	27.1	27.1	27.3	26.8	27.2
1287189	27.8	28.6	28.8	28.9	27.8	28.1	28.7	28.0
1287187	27.7	28.5	29.2	27.9	27.9	28.9	27.7	29.1
1187076	27.3	27.1	28.0	27.4	27.2	27.2	26.2	26.9
1288188	26.5	27.0	26.8	26.4	26.5	26.5	26.4	26.4
1187075	28.0	28.5	28.6	29.0	28.5	28.6	28.0	27.9
1287192	29.0	28.9	27.8	27.3	27.7	28.2	27.9	28.4
0787138	28.1	28.0	27.9	28.0	28.2	28.0	28.6	28.1

Table 47. Input Port Crosstalk Losses (Ports 1-8)

Coupler ID#	Minimum Average Crosstalk Loss (dB) *Input Port #*							
	9	10	11	12	13	14	15	16
1187054	28.0	27.9	28.1	28.4	28.0	28.1	28.0	29.4
1187078	27.4	27.4	27.3	27.9	27.6	27.9	28.3	29.6
1187072	28.0	27.4	27.6	27.9	27.6	27.6	27.6	27.7
1187074	28.2	28.0	28.0	28.1	27.8	27.8	28.0	28.1
1287191	27.5	27.7	27.6	27.9	27.7	27.9	27.3	27.8
0987002	28.3	28.6	29.6	28.9	28.7	28.2	29.6	28.9
1187055	27.2	27.6	27.4	29.0	27.0	26.9	27.2	27.2
1287185	27.6	27.6	27.4	27.6	27.6	27.2	27.6	27.8
1187081	27.7	28.2	27.4	27.6	27.5	27.5	27.5	27.5
1187079	28.8	28.0	28.5	28.5	28.2	27.7	28.0	29.2
1287186	26.6	26.3	26.4	26.6	26.7	26.3	26.4	26.5
1187080	27.0	27.0	27.1	27.2	27.0	27.1	27.3	27.1
1287189	28.0	28.6	27.6	27.6	27.7	28.3	27.8	29.5
1287187	28.5	27.8	27.7	28.1	27.2	27.6	27.7	28.2
1187076	27.0	27.2	27.2	26.4	27.2	27.1	27.4	27.1
1288188	26.3	26.7	26.5	26.6	26.8	26.7	26.4	26.0
1187075	27.8	27.9	28.0	27.1	27.9	28.4	27.5	28.3
1287192	28.1	27.8	28.3	27.3	27.7	27.6	27.4	27.6
0787138	28.0	27.9	27.9	28.1	28.2	27.9	27.6	27.6

Table 48. Input Port Crosstalk Losses (Ports 9-16)

D.3.3 Coupler Loss Summaries

Coupler ID#	Input-to-Input Losses (dB) (max)	(min)	Input-to-Output Losses (dB) (max)	(min)	(avg)	Coupler Loss (dB) Uniformity†
1187054	29.3	27.8	15.9	13.2	14.4	2.7
1187078	26.7	25.9	14.9	13.1	14.2	1.8
1187072	27.1	26.2	14.9	13.1	13.8	1.8
1187074	27.5	26.6	15.3	12.7	14.2	2.6
1287191	26.4	26.1	14.9	13.1	14.1	1.8
0987002	29.6	27.7	15.8	12.7	14.6	3.1
1187055	29.0	27.1	14.9	13.8	14.0	1.1
1287185	26.6	25.9	14.9	13.7	14.3	1.2
1187081	26.3	25.9	16.2	13.5	14.4	2.7
1187079	29.2	27.8	15.7	13.8	14.6	1.9
1287186	27.2	26.1	16.7	14.1	15.5	2.6
1187080	28.1	26.4	16.6	12.5	13.9	4.1
1287189	29.5	27.6	15.9	12.7	14.8	3.2
1287187	29.2	27.6	15.5	13.1	14.6	2.4
1187076	27.2	26.0	14.8	12.4	13.9	2.4
1288188	26.6	26.0	16.7	15.2	15.8	1.5
1187075	26.7	26.0	15.0	13.8	14.5	1.2
1287192	28.9	27.3	16.5	13.5	15.0	3.0
0787138	26.1	25.4	14.0	11.9	13.5	2.1

Table 49. Coupler Loss Summary

† Coupler Loss Uniformity refers to the difference between maximum and minimum input-to-ouput port loss measurements. The coupler loss uniformity is a measure of how good the coupler is. An ideal coupler will have a zero uniformity for every port. It couples optical energy evenly among all its ports.

E. Fiber Termination Procedures

The following two sections outline proper optical fiber termination procedures. The first section includes literature from AMP incorporated on how to install both **ST** and **FSD** type connectors. The second section outlines problems encountered and additional information used to terminate fiber sections used in the Mohler Fiber Optic Network.

The first section includes AMP Instruction Sheets (IS) 6935 and 9373. IS 9373 covers the application of AMP Fixed-Shroud Duplex (FSD) Connector 501780-1 to fiber optic cable. IS 6935 sheet covers the application of AMP Optimate 2.5-mm Bayonet Connector (ST) Kit 501380-1 and -2 to fiber optic cable.

E.1 AMP Termination Procedures

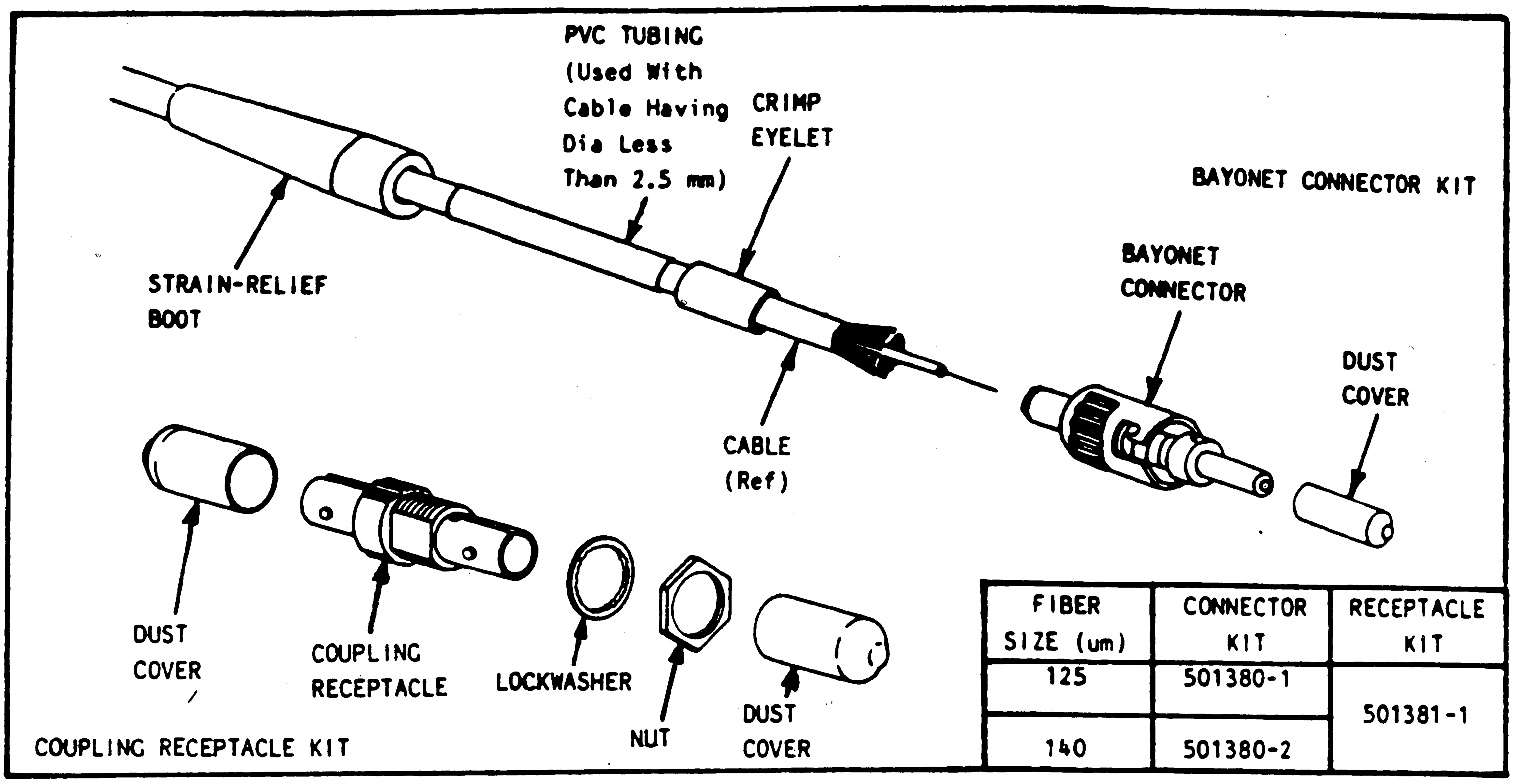
The following pages are included with permission obtained from AMP Incorporated. The two documents, IS 6935 and 9373, describe proper termination procedures for their ST and FSD type connectors respectively.

E.1.1 AMP Instruction Sheet 6935

AMP
AMP INCORPORATED
Harrisburg, Pa 17105

AMP* OPTIMATE* 2.5-MM BAYONET CONNECTOR KIT 501380-[] AND COUPLING RECEPTACLE KIT 501381-1

Instruction Sheet
IS 6935
9/16/86
RELEASED



FIBER SIZE (um)	CONNECTOR KIT	RECEPTACLE KIT
125	501380-1	501381-1
140	501380-2	

Fig. 1

1. INTRODUCTION

This instruction sheet (IS) covers the application of AMP OPTIMATE 2.5-mm Bayonet Connector Kit 501380-1 and -2 to fiber-optic cable.

Read this material thoroughly before starting assembly.

NOTE Dimensions on this instruction sheet are in millimeters first, with inch equivalents in parentheses.

2. DESCRIPTION

Figure 1 shows the bayonet connector kit which consists of a bayonet connector, strain-relief boot, crimp eyelet, and dust cover. PVC tubing, used only with cables having a jacket diameter of less than .1 in. (2.5 mm), is also included. Simplex fiber-optic cable having a 125- or 140-um glass fiber, and a cable diameter ranging from 2.4 to 3 mm (.09 to .12 in.), can be used with the connector. A green dot on the connector body identifies the 140-um connector.

The coupling receptacle kit is used to mate two bayonet connectors. A coupling receptacle, lockwasher, nut, and two dust covers make up the receptacle kit. The receptacle can be used in free-hanging applications, or it can be mounted in a panel.

3. ASSEMBLY PROCEDURE

A. Required Tools and Materials

The following tools and materials are required for applying the bayonet connector to optical fibers:

- AMP .012-in. Fiber Stripper 501013-1
- AMP Scissors 501014-1
- AMP Crimping Tool 58190-4 with Die Assembly 58289-1; or Hand Tool 220190-1 with Die Assembly 58299-1
- AMP Scribe Tool 228793-1
- AMP Polishing Bushing 501467-1
- AMP Polishing Plate 501197-2
- AMP 5-um Polishing Film 228433-8
- AMP 1-um Polishing Film 228433-7
- AMP Epoxy 501195-4
- AMP Microscope 501196-1 or equivalent
- Wire stripper with No. 16 AWG position
- Resilient backing 501523-1
- Syringe 501473-2

B. Preparing Fibers

WARNING Be very careful to dispose of fiber-optic ends properly. The fibers create slivers that can easily puncture the skin and cause irritation.

WARNING Always wear safety glasses when working with optical fibers.

1. Slide strain-relief boot (small end first) over the cable jacket (see Figure 1). If the cable has a jacket diameter of less than .1 in. (2.5 mm), slide the PVC tubing onto the cable next.

2. Slide the crimp eyelet onto the cable (folded-under end first). See Figure 1.

3. Strip cable jacket to the dimension shown in Figure 2 using the No. 16 AWG position of a wire stripping tool.

4. Fold strength members back over cable jacket.

5. Strip cable buffer to dimension shown in Figure 2 using .012-in. Fiber Stripper 501013-1.

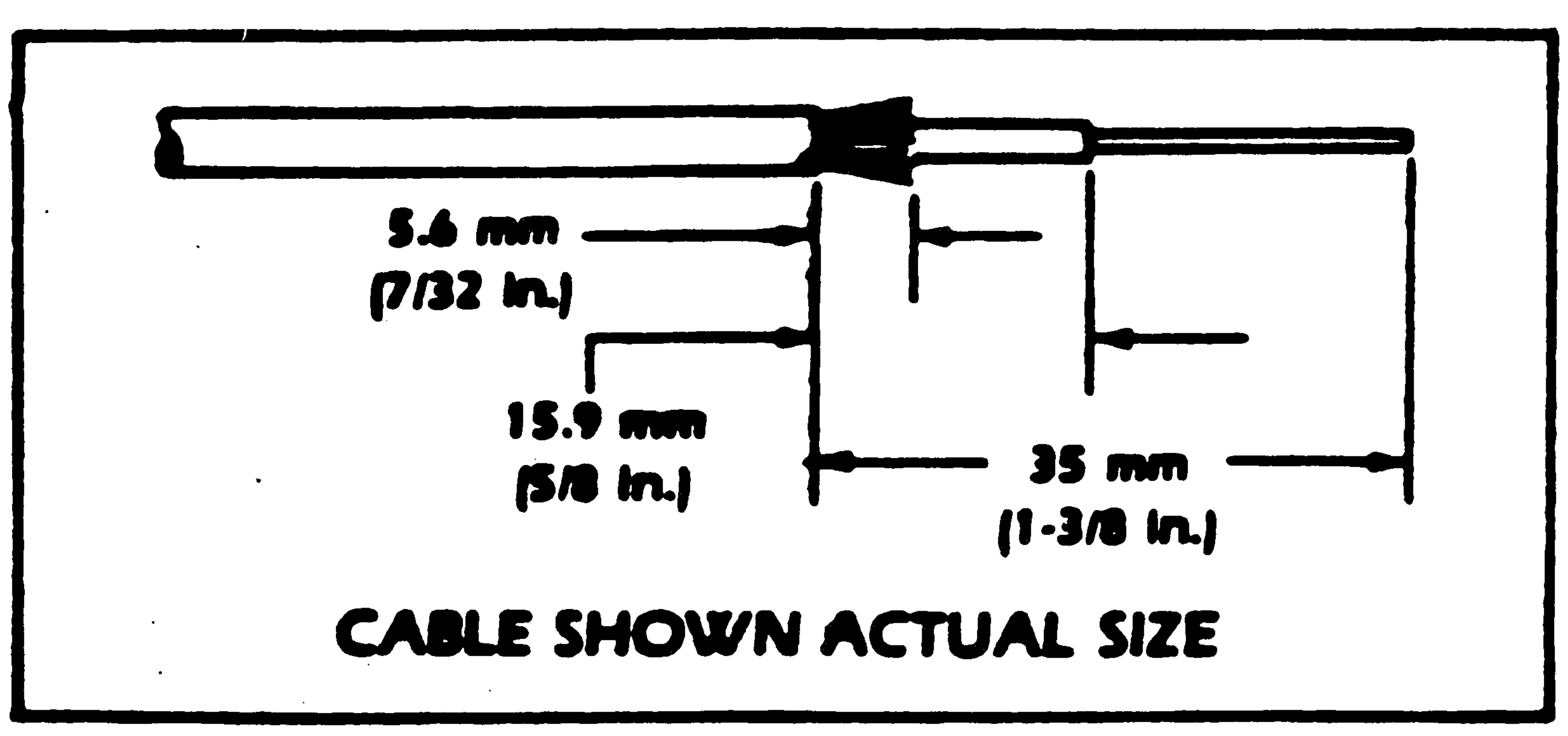


Fig. 2

6. Trim strength members to dimension shown in Figure 2 using Scissors 501014-1.

7. Evenly fan out strength members from buffer.

C. Terminating Fibers

1. Remove the separating clip from the epoxy package and mix the epoxy thoroughly for 20 to 30 seconds. Use of AMP Epoxy Mixer 501202-1 is recommended. Open the tube and pour the epoxy into a dispensing tray or onto the foil.

2. Fill a syringe with epoxy.

3. Hold connector with knurled end up. Insert needle of syringe as far as possible into the support sleeve of the connector. See Figure 3A.

4. Inject epoxy until a small bead, approximately .74 mm (.030 in.) in diameter, appears at the ceramic end. Do not let the bead get too large or smear.

5. Back the needle out and continue to inject epoxy until the bore is one-half to three-fourths full.

6. Apply a drop of epoxy to the outside (knurl) of the support sleeve and distribute it evenly (see Figure 3B). Do not get any epoxy on the nut/spring area.

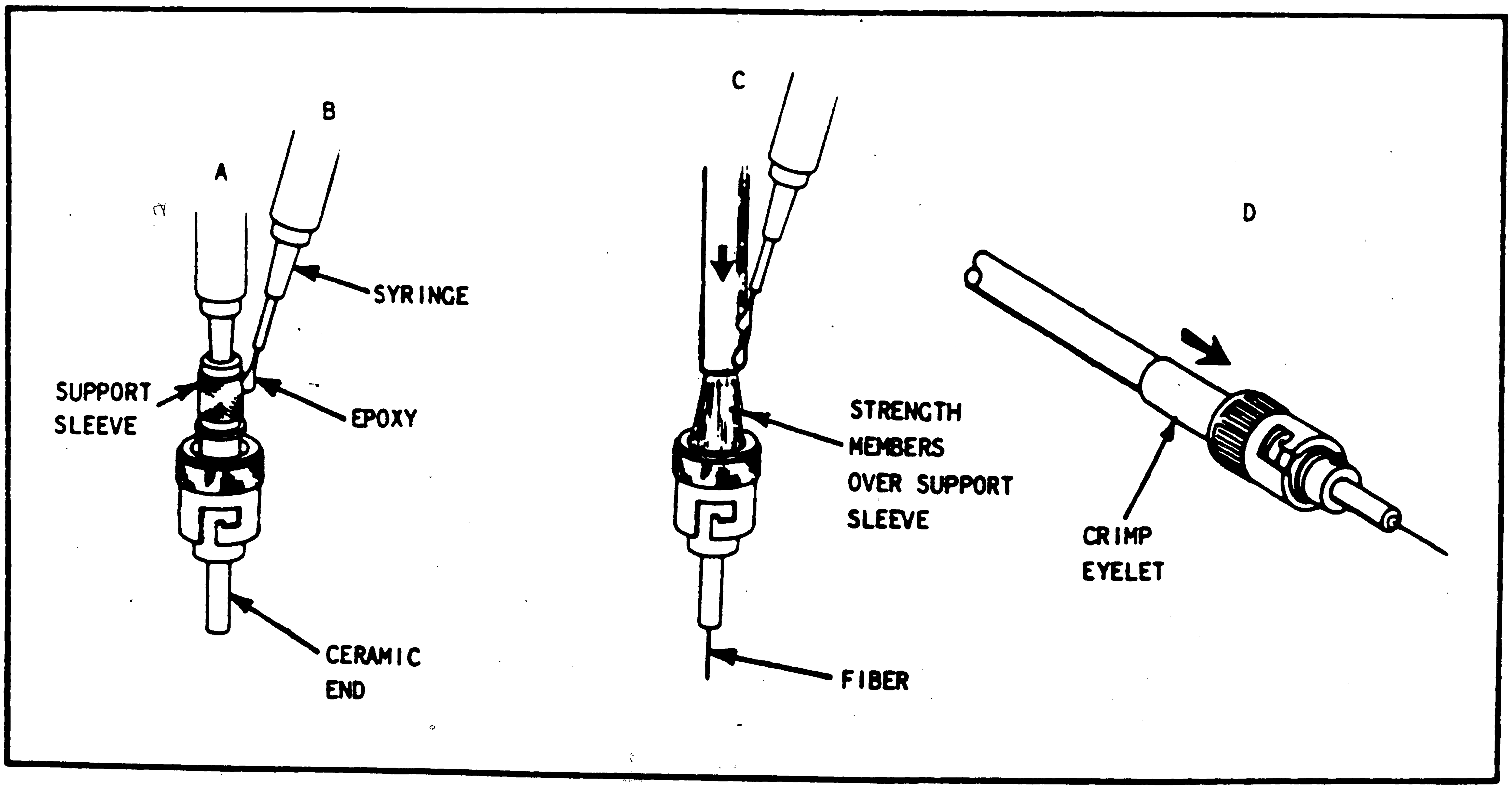


Fig. 3

7. Insert the fiber as far as possible into the connector (see Figure 3C). The strength members must spread over the outside of the knurled support sleeve. The fiber should appear at tip of ceramic end.

8. Twist the cable and, at the same time, move it back and forth axially about 1.5 mm (.060 in.) to distribute epoxy in the ceramic capillary bore.

9. Put epoxy around the cable jacket where the crimp eyelet will contact the jacket.

10. Slide crimp eyelet toward connector until it bottoms on connector shoulder, trapping strength members against the knurl (see Figure 3D). If PVC tubing is used, slide it under the crimp eyelet until the tubing bottoms.

D. Crimping

Using Hand Tool 58190-4

NOTE: See IS 9047, packaged with Hand Tool 58190-4, and the instruction sheet packaged with Die Assembly 58289-1, for detailed instructions.

1. Install Die Assembly 58289-1 in Hand Tool 58190-4.

2. Squeeze the handles on the hand crimping tool until the ratchet releases. Open the tool fully.

3. Place the connector in the dies so that the coupling nut rests against the locator. See Figure 4.

4. Squeeze the crimping tool handles shut to crimp the eyelet.

Using Hand Tool 220190-1

NOTE: See IS 2901, packaged with Hand Tool 220190-1, and the instruction sheet packaged with Die Assembly 58299-1, for detailed instructions.

1. Install Die Assembly 58299-1 in Hand Tool 220190-1.

2. Squeeze the handles on the hand crimping tool until the ratchet releases. Open the tool fully.

3. Place the connector in the dies so that the flange in front of the support sleeve rests against the side of the dies. See Figure 5.

4. Squeeze the crimping tool handles shut to crimp the eyelet.

E. Curing

Hang the connector vertically with the tip down and cure at either:

a. 25°C (72°F) for 24 hours; or
b. 65°C (150°F) for 4 hours

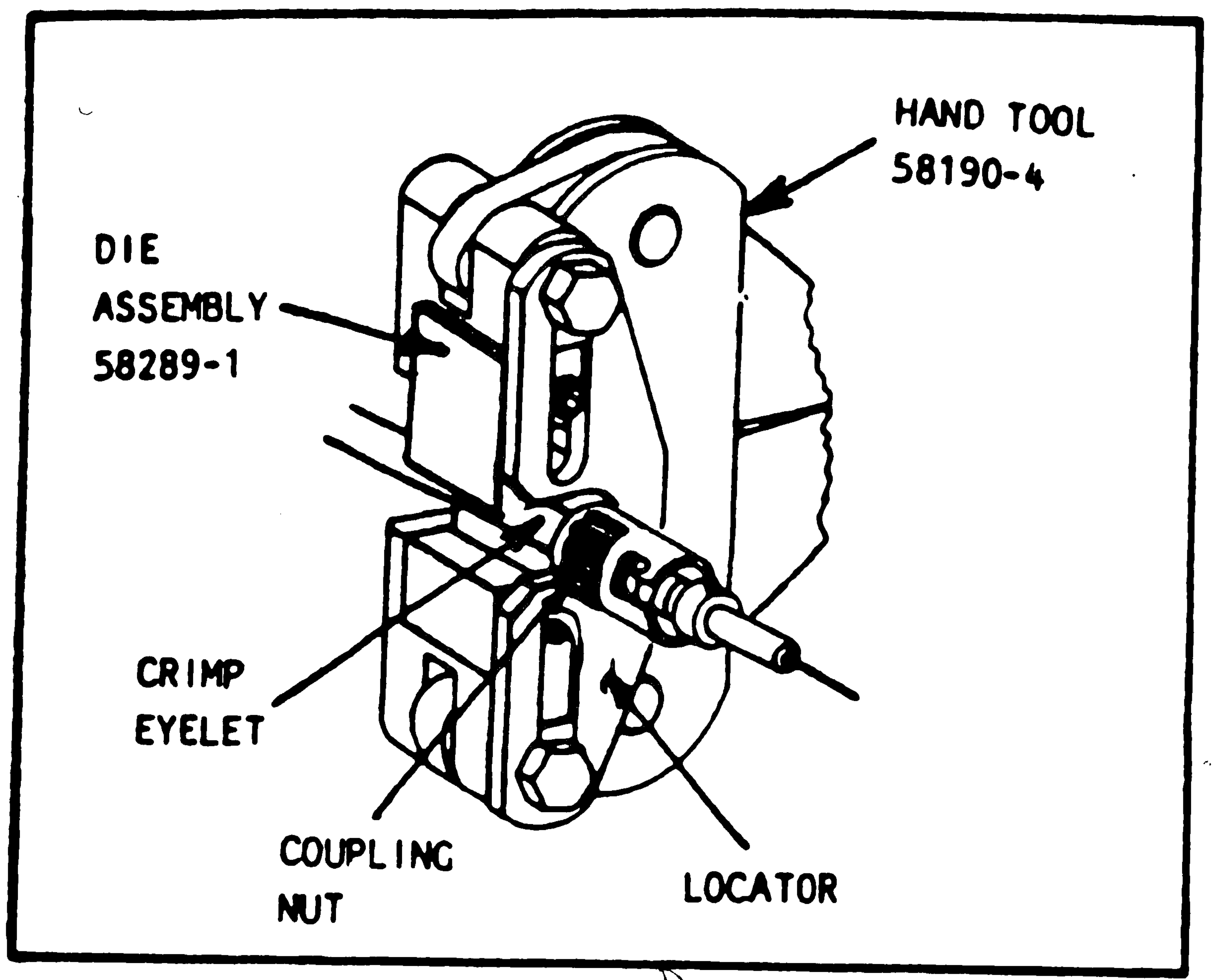


Fig. 4

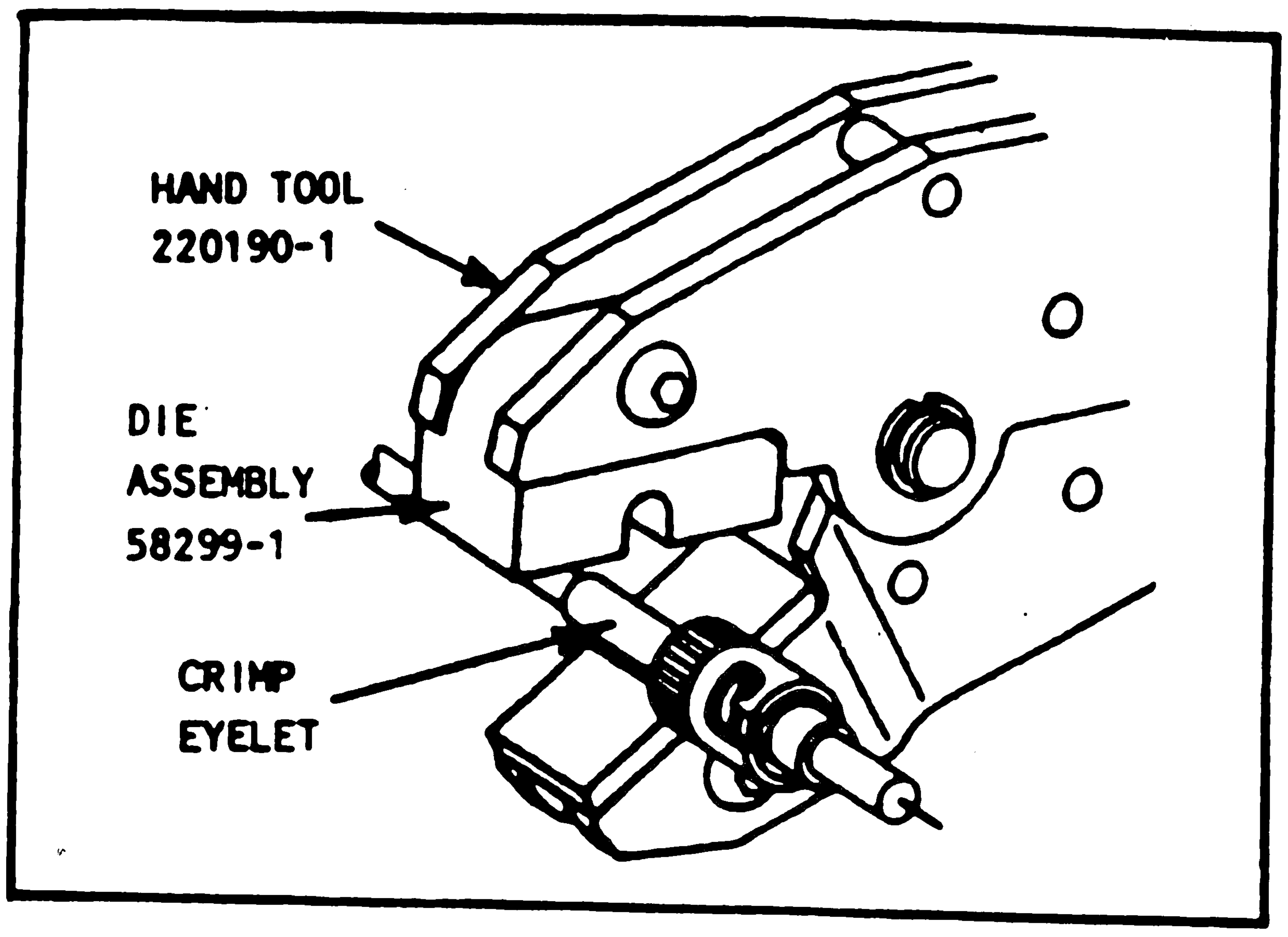


Fig. 5

F. Polishing the Fiber

Polishing may be done by hand with Polishing Bushing 501467-1 or with AMP Polishing Machine 501186-1 along with Polishing Bushing 501477-1. This sheet describes hand polishing. For information on using the polishing machine, see IS 9107, supplied with the machine.

1. Firmly support the connector assembly.

WARNING SAFELY DISPOSE OF THE EXCESS FIBER. A handy method is to put a small piece of masking tape on the fiber before scribing it. The fiber is then easily retrieved and disposed of.

2. With the beveled edge of Scribe Tool 228793-1 facing up, lightly scribe the fiber. Then pull the fiber straight away from the connector. See Figure 6.

3. Thread the polishing bushing onto the connector. See Figure 7. Lock the connector in place on the polishing bushing using the connector's coupling nut.

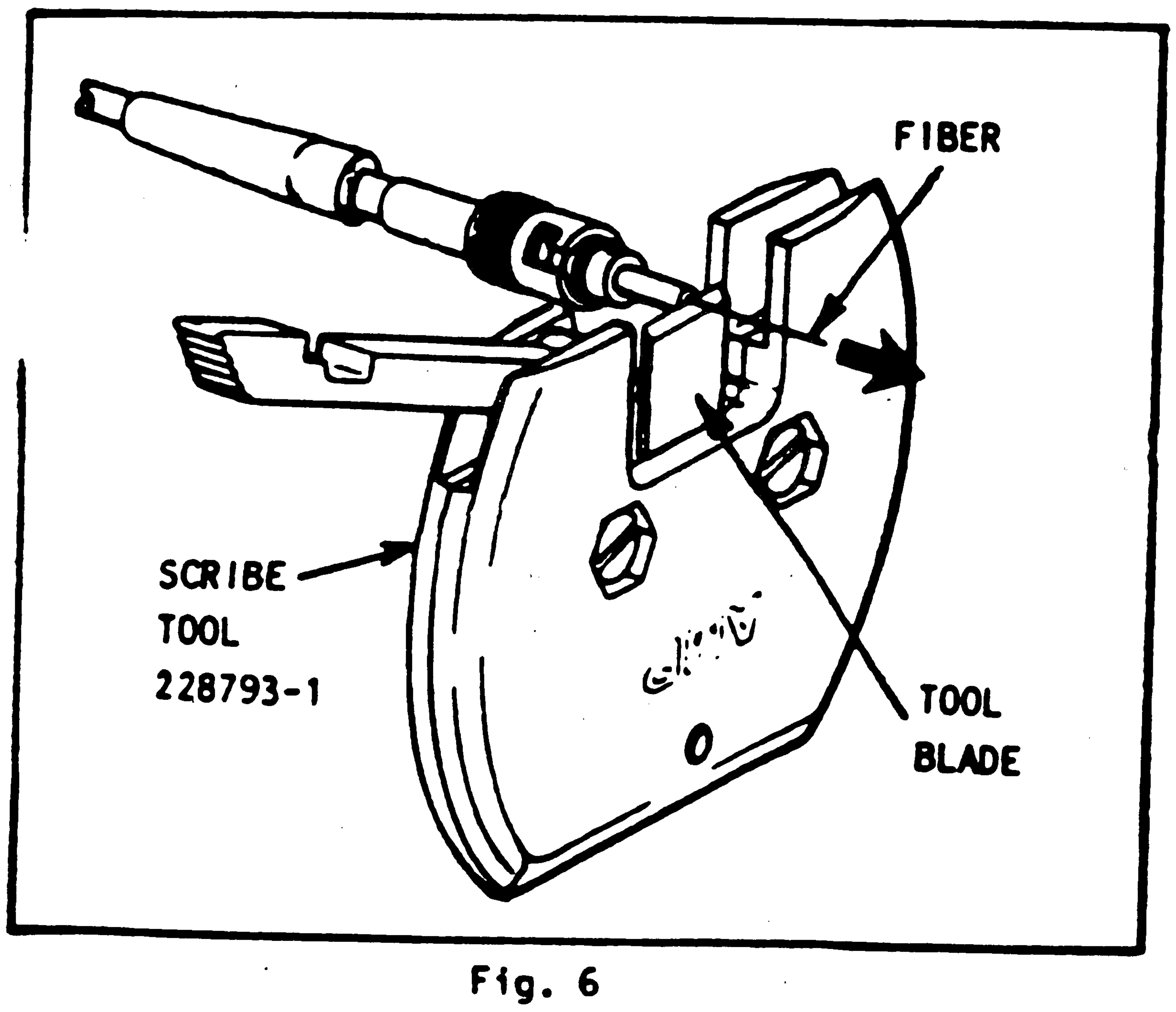


Fig. 6

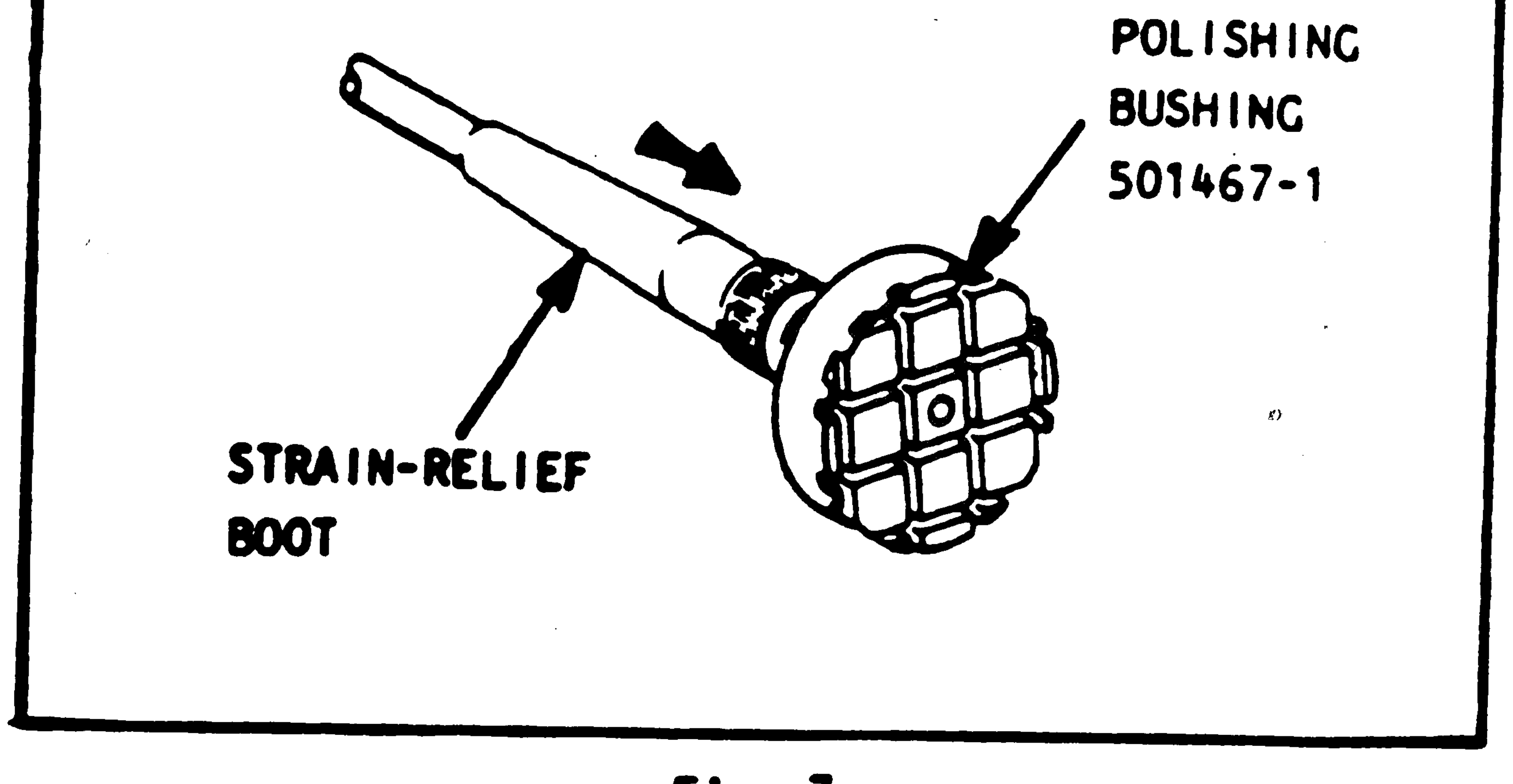


Fig. 7

11. Remove the polishing bushing. Carefully dry the connector with a soft cloth or tissue.

12. Place the dust cover over the connector if the connector is not going to be used immediately.

G. Using Coupling Receptacle Kit

The coupling receptacle can be used free-hanging, or it can be mounted on a panel. To mount the receptacle in a panel:

1. Prepare the panel. See Figure 10 for the cutout dimensions.

2. Assemble the receptacle as shown in Figure 10.

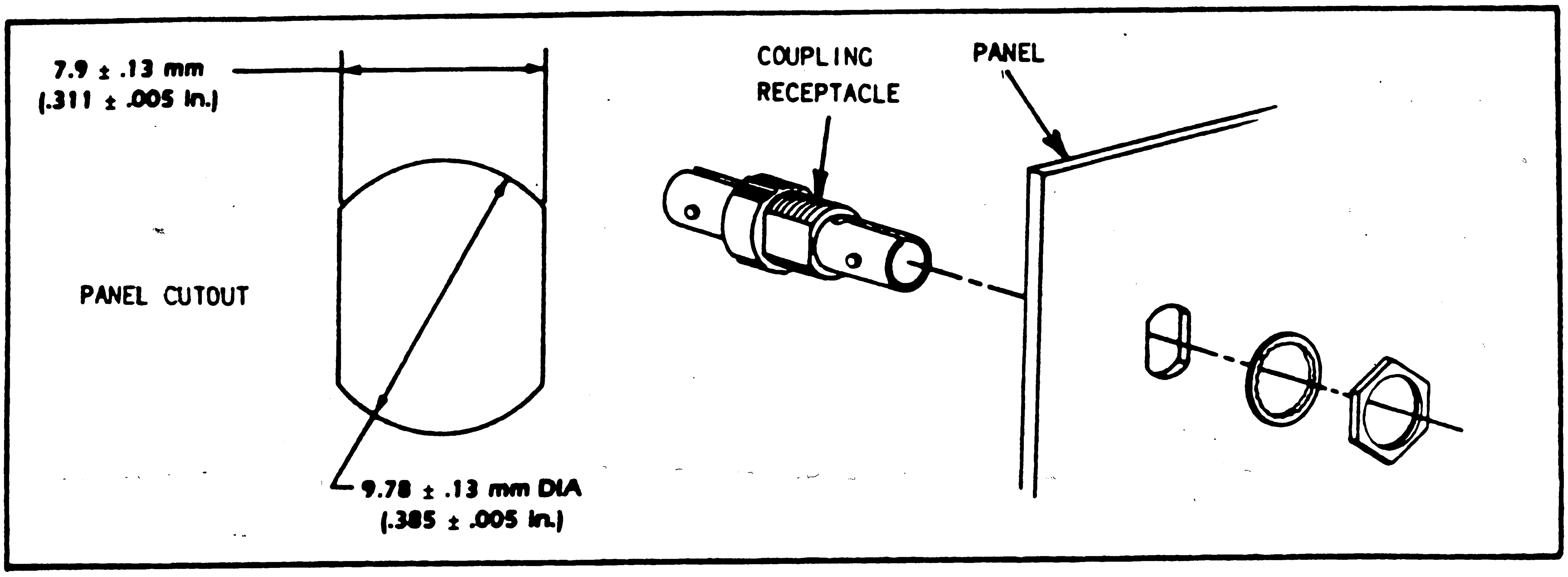


Fig. 10

4. Slide strain-relief boot over eyelet and connector shoulder. See Figure 7. Make sure that strain-relief boot slides over connector shoulder and locks into place.

5. Place the resilient backing on a tilted glass plate.

6. Place 5-um film on a resilient backing and run water over the film.

CAUTION During polishing, the water and lapping film must be kept clean to prevent abrasive particles from scratching or chipping the fiber surface.

7. Polish in an elongated figure-8 motion. See Figure 8. Periodically check ceramic tip and stop when enough epoxy has been removed that the epoxy's color begins to change from dark blue to light blue.

8. Replace the 5-um film with 1-um film. Keep the resilient backing between the film and the plate.

9. Polish for 30 to 90 seconds on the 1-um film.

WARNING Never inspect or look into the end of a fiber when optical power is applied to the fiber. The infrared light used, although it cannot be seen, can cause injury to the eyes.

10. Inspect the polished ceramic tip under the magnifier or microscope. See Figure 9. Check for the following:

- Scratches on the ceramic tip indicate a need for further polishing with 1-um film.

- Small chips in the outer rim of the fiber are permissible. Large chips, or chips in the center of the fiber, mean either that further polishing is needed or that the termination is unacceptable and the fiber must be reterminated.

NOTE See IS 9111 for information on the use of AMP Microscope 501196-1.

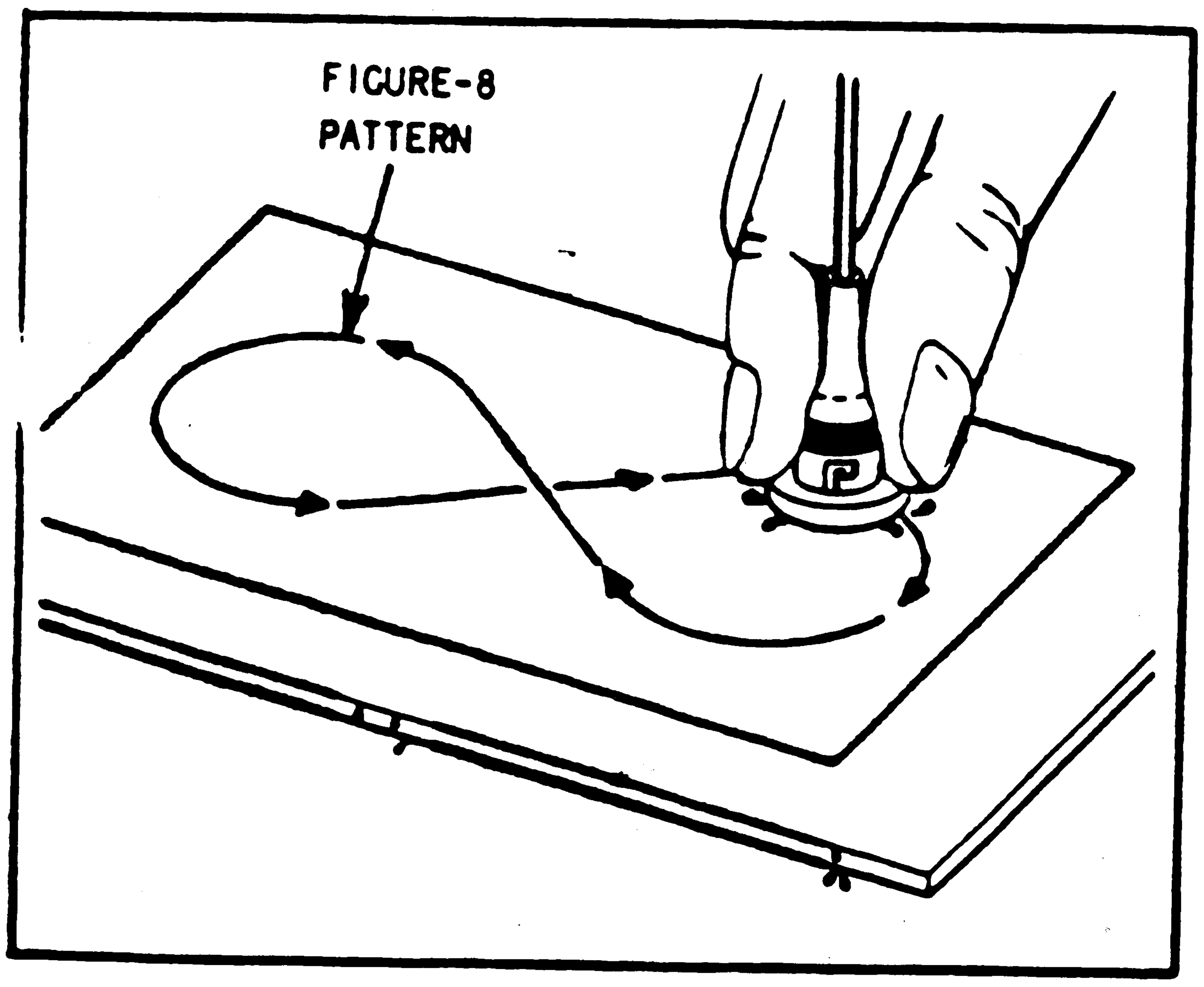


Fig. 8

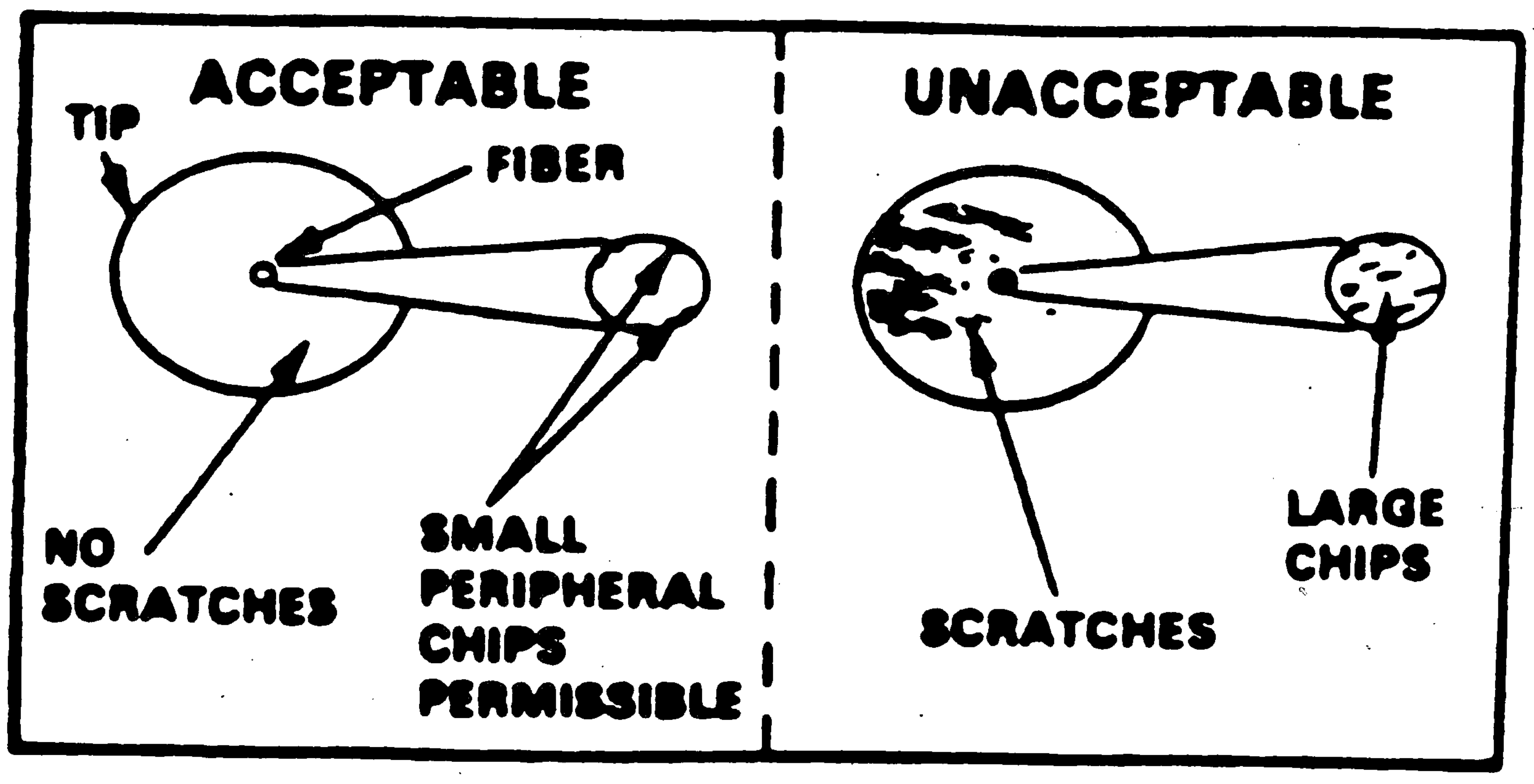


Fig. 9

E.1.2 AMP Instruction Sheet 9378

AMP

CUSTOMER HOTLINE 1 800 722-1111

AMP* OPTIMATE* FIXED-SHROUD DUPLEX (FSD) CONNECTOR 501780-1

Instruction Sheet

IS 9373

RELEASED 12-9-87

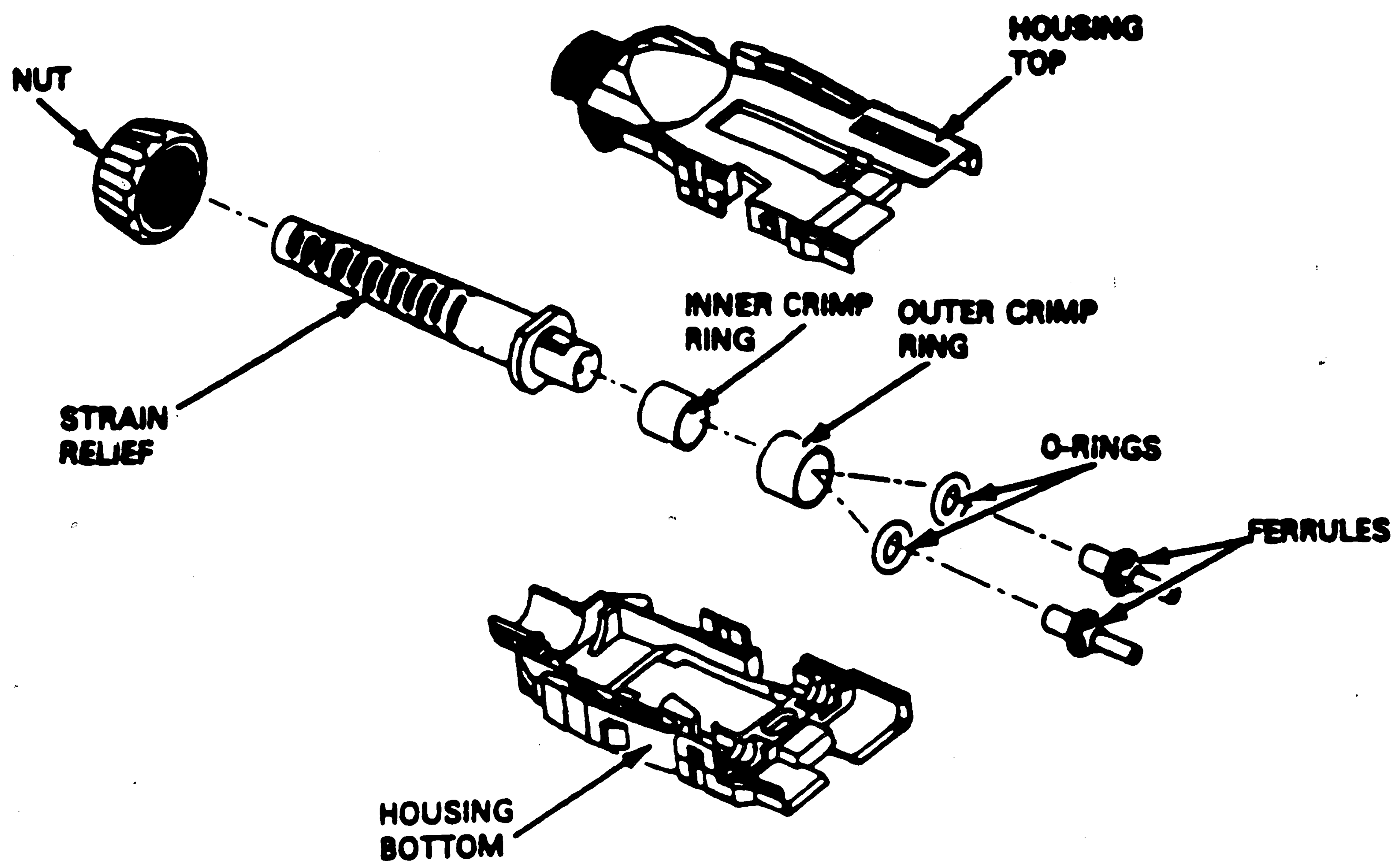


Fig. 1

1. INTRODUCTION

This instruction sheet (IS) covers the application of AMP Fixed-Shroud Duplex Connector 501780-1 to fiber-optic cable.

Read this material thoroughly before starting assembly.

NOTE *Dimensions on this instruction sheet are in millimeters first, with inch equivalents in parentheses.*

2. DESCRIPTION

Figure 1 shows the Fixed-Shroud Duplex Connector which is made up of connector housing halves, two ferrules, two O-rings, inner and outer crimp rings, strain relief, and nut. The connector can be used with 62.5/125-μm duplex fiber-optic cable.

3. ASSEMBLY PROCEDURE

A. Required Tools and Materials

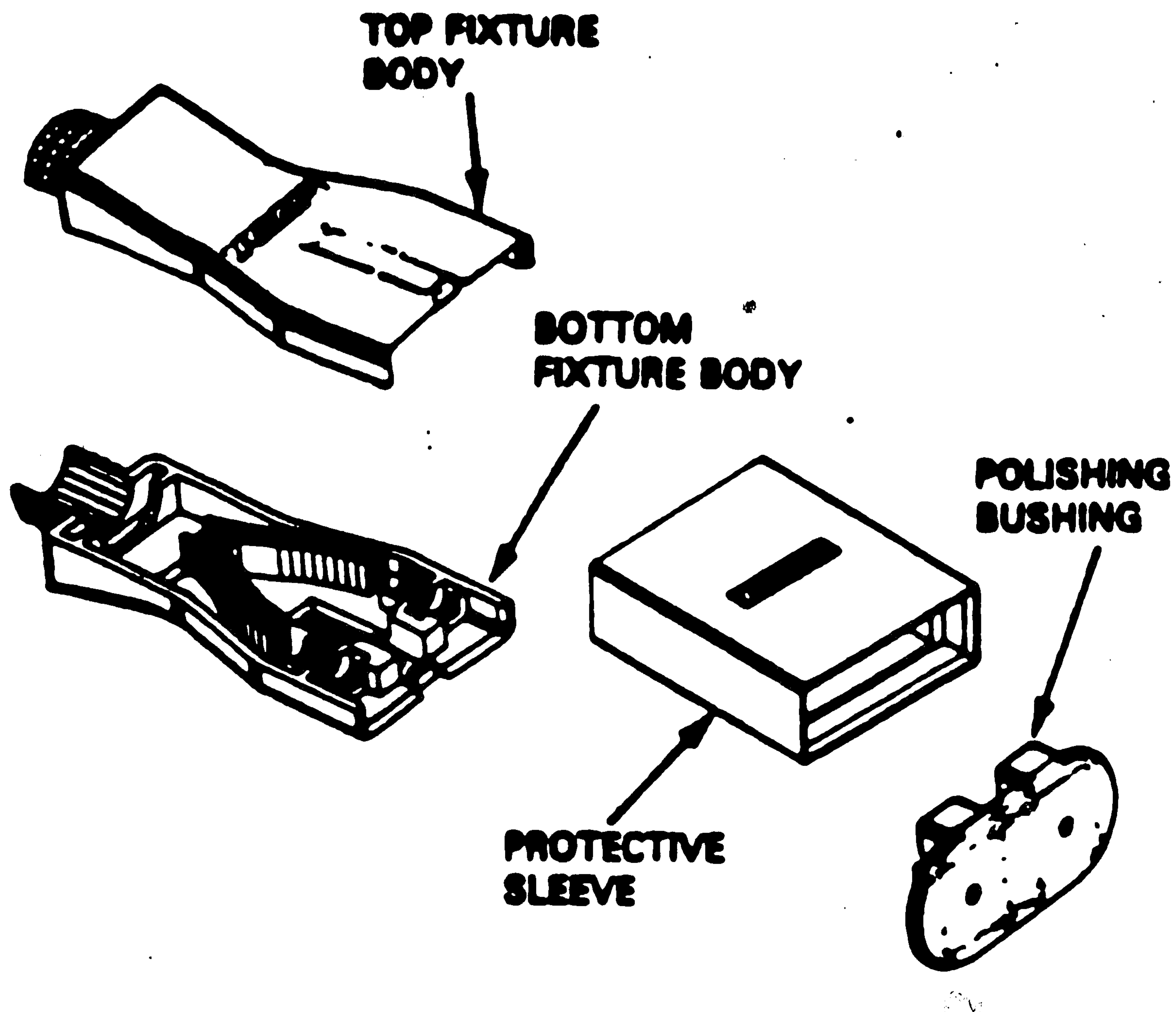
The following tools and materials are required for applying the connector to optical fiber:

Tools

- Cable Stripper 501198-1
- Assembly Fixture Kit 501795-1
- Scribe Tool 228793-1
- Hand Tool 69710-1
- Die Assembly 220037-1
- Epoxy Applicator 501473-2
- Strip Dimension Reference Card

Consumable Items

- Epoxy 501195-1
- .3-μm Polishing Film 228433-5
- 1-μm Polishing Film 228433-4
- 5-μm Polishing Film 228433-3
- Resilient Pads 501523-1



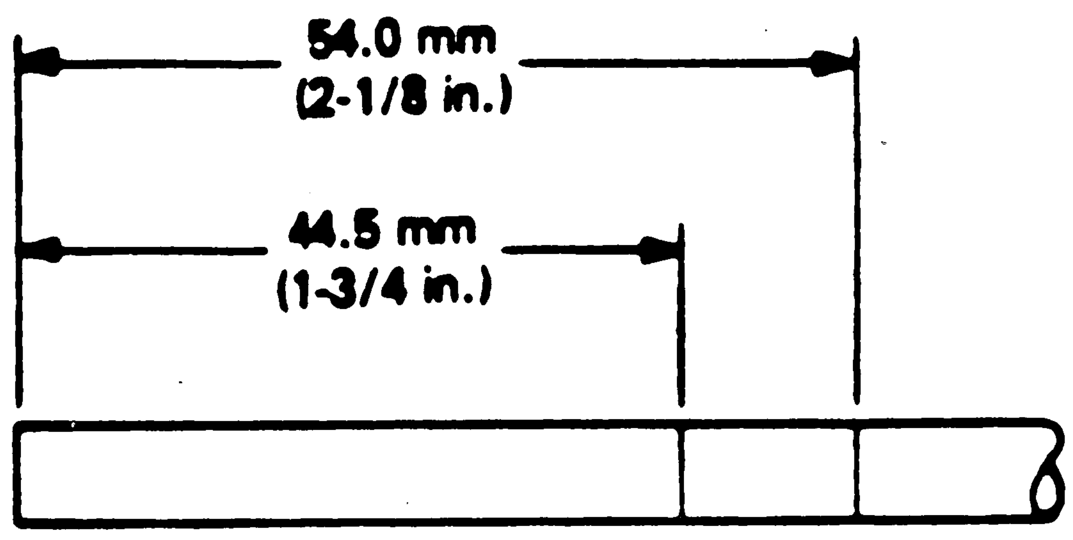
ASSEMBLY FIXTURE KIT

B. Preparing Fibers

WARNING *Always wear safety glasses when you work with optical fibers. Be very careful to dispose of fiber ends properly. The fibers create slivers that can easily puncture the skin and cause irritation.*

1. Cut the cable to length.

2. Mark the end of the cable for stripping, as shown in Figure 2, but do not strip the cable yet.



CABLE SHOWN ACTUAL SIZE
Fig. 2

3. Slide the nut and strain relief (with inner crimp ring installed) over the cable. See Figure 3.

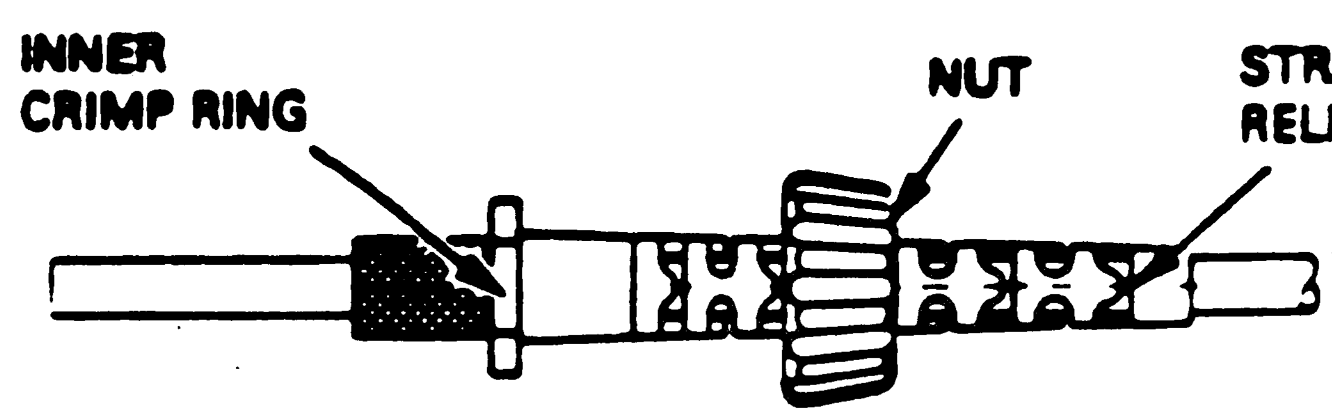


Fig. 3

4. Strip the outer jacket to the first mark (44.5 mm (1-3/4 in.)) using Cable Stripper 501198-1. See Figure 4. Save the outer jacket for use later in assembly.

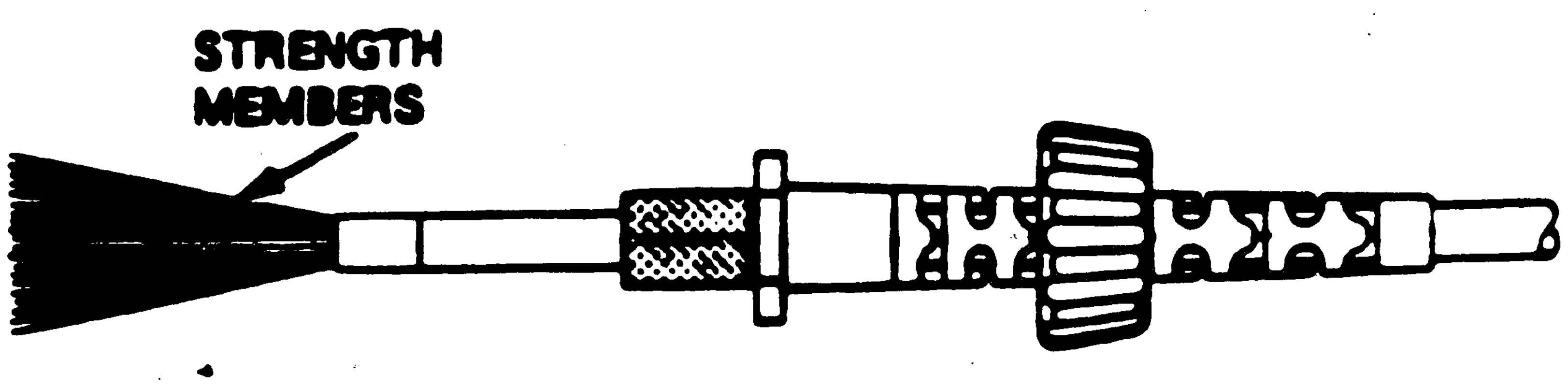


Fig. 4

5. Trim the strength members back to the jacket (see Figure 5). Be careful that you don't damage the fibers.

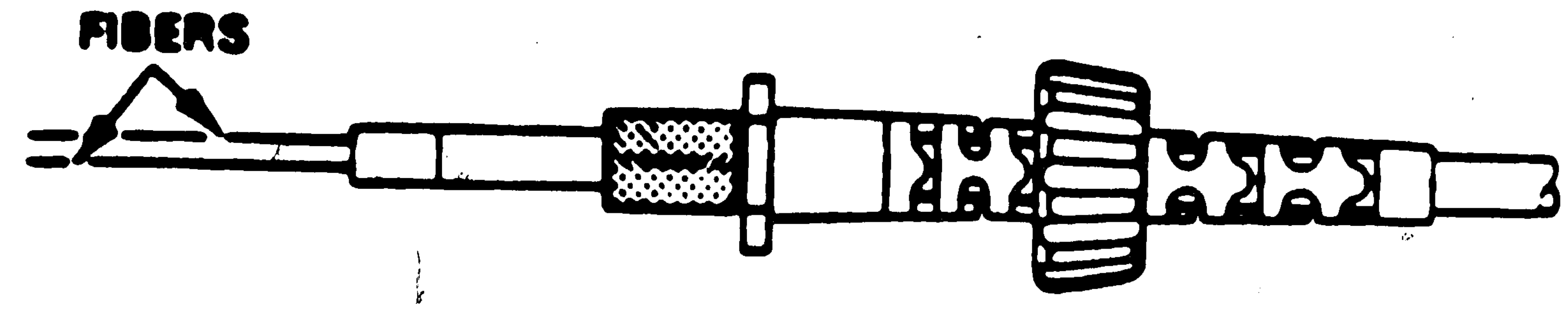


Fig. 5

6. Strip the outer jacket to the second mark. Position the end of the strain relief even with the end of the outer jacket. See Figure 6.

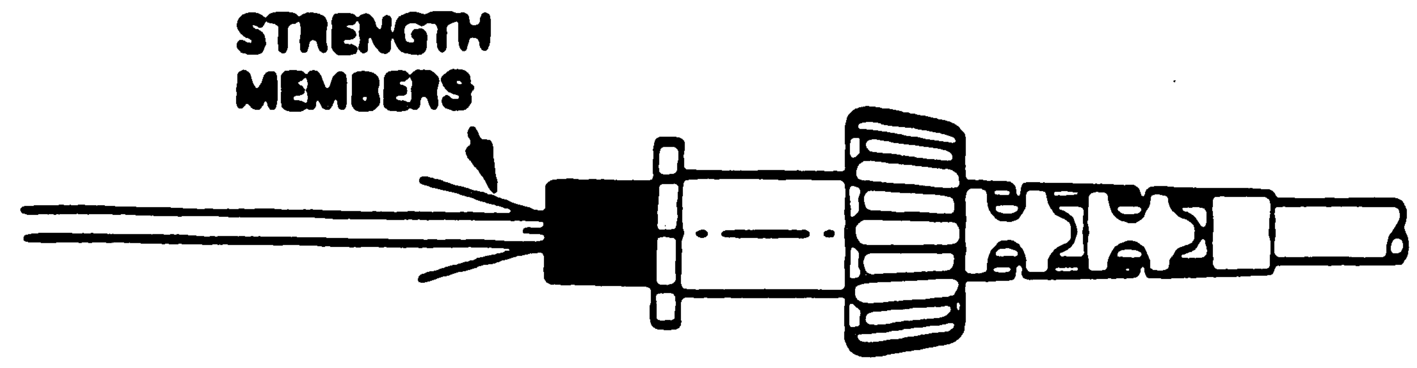


Fig. 6

7. Gently fold the fibers to the side. Pinch the strength members and gently pull them sideways to separate all strength members from the fibers.

8. Slide the piece of outer jacket (stripped previously) over the fibers and down against the strength members. Push lightly on the piece of jacket and rotate it back and forth to fan out the strength members in an even circular pattern. See Figure 7.

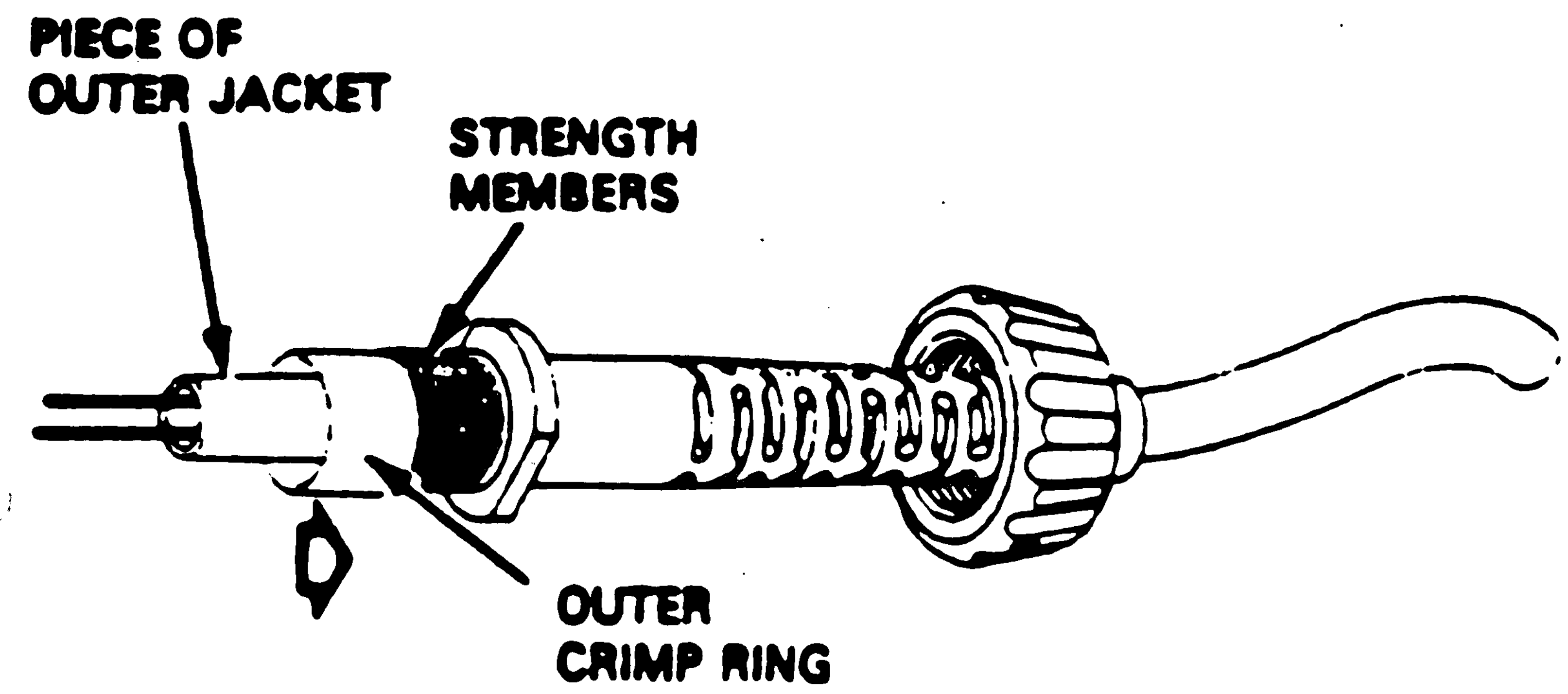


Fig. 7

9. Slip the outer crimp ring over the tubing. While holding the tubing pressed against the strength members, support the strain relief and push the outer crimp ring over the strength members so that they are folded back over the inner crimp ring. See Figure 7.

10. Crimp the outer crimp ring using Hand Tool 69710-1, equipped with Die Assembly 220037-1. See Figure 8. The dies can also be used in Pneumatic Tool 69365-2. Be careful not to let the strength members or the inner crimp ring slide out of position. Discard the piece of outer jacket.

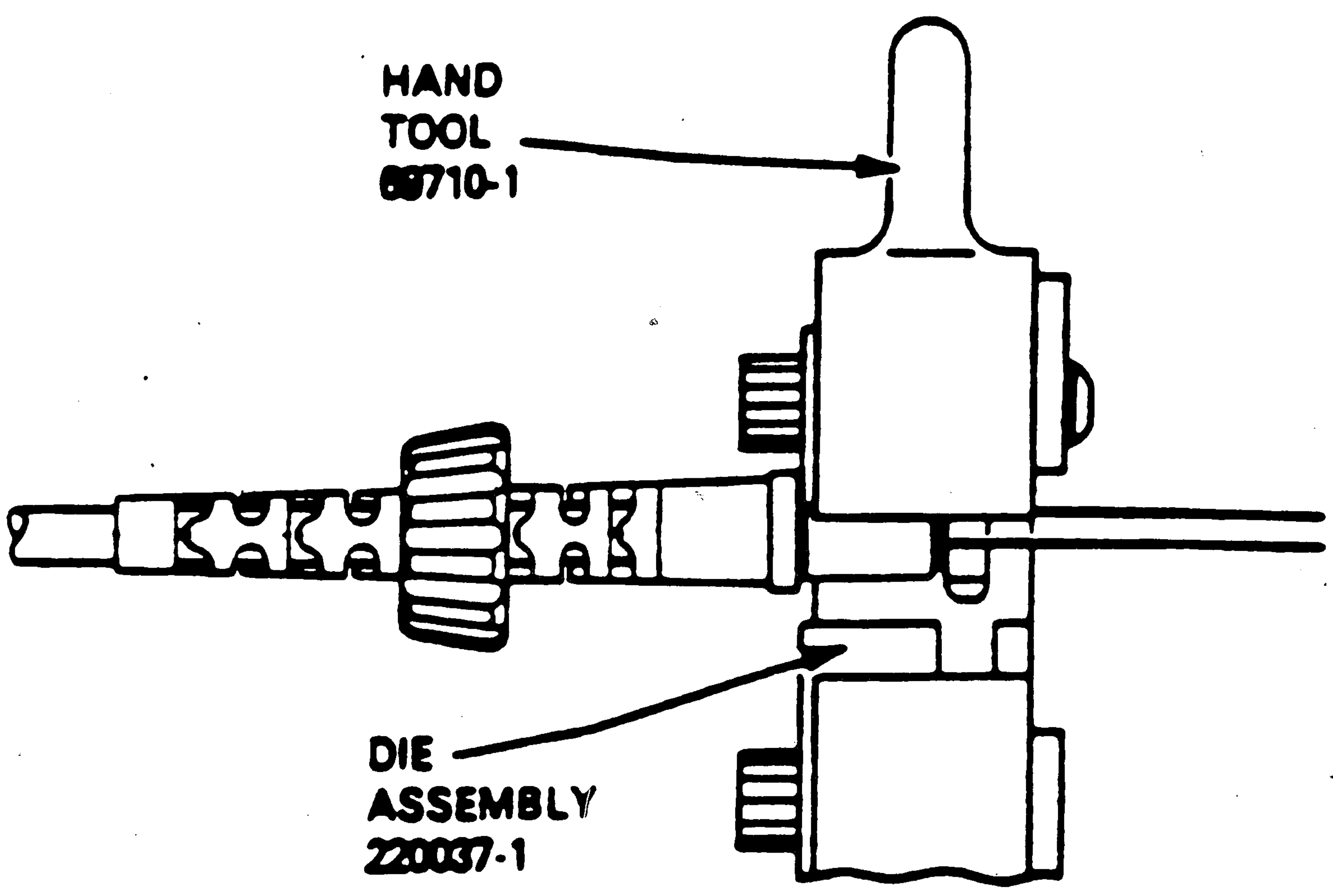


Fig. 8

11. Strip the buffer from both fibers according to the dimension shown in Figure 9.

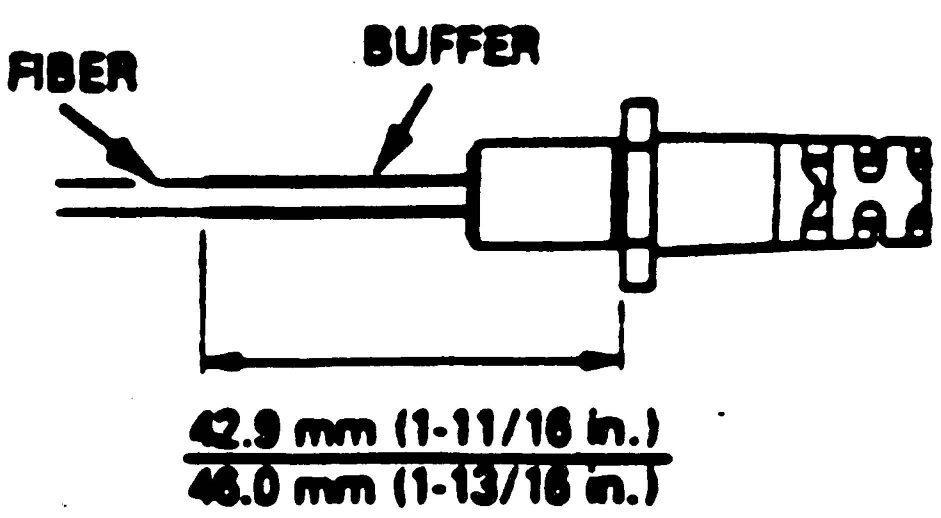


Fig. 9

12. Clean the fibers with an alcohol preparation pad and place the strain relief and fibers in the bottom fixture body of Assembly Fixture Kit 501795-1 as shown in Figure 10.

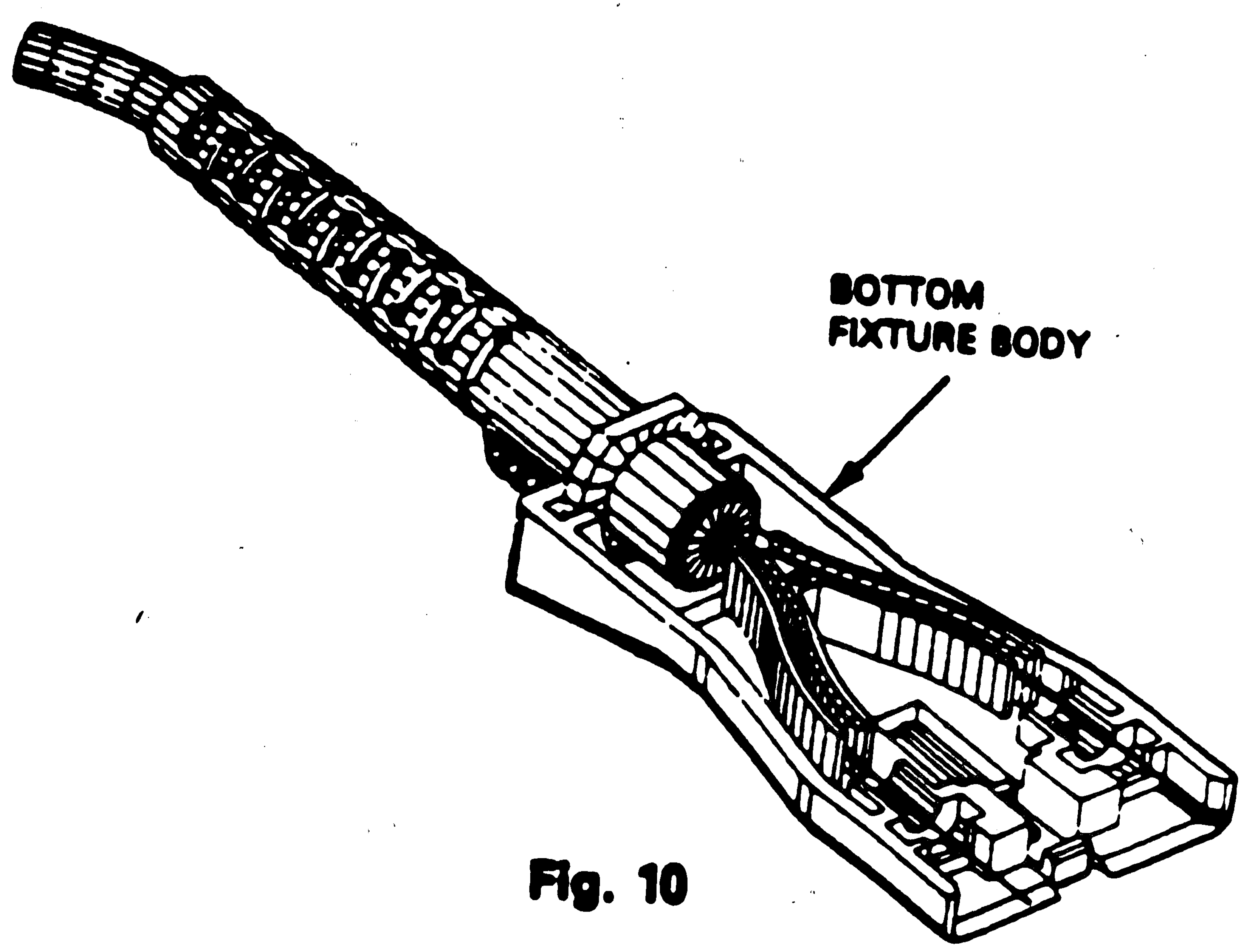


Fig. 10

13. Place an O-ring on the rear of each ferrule, against the ferrule shoulder (see Figure 11).

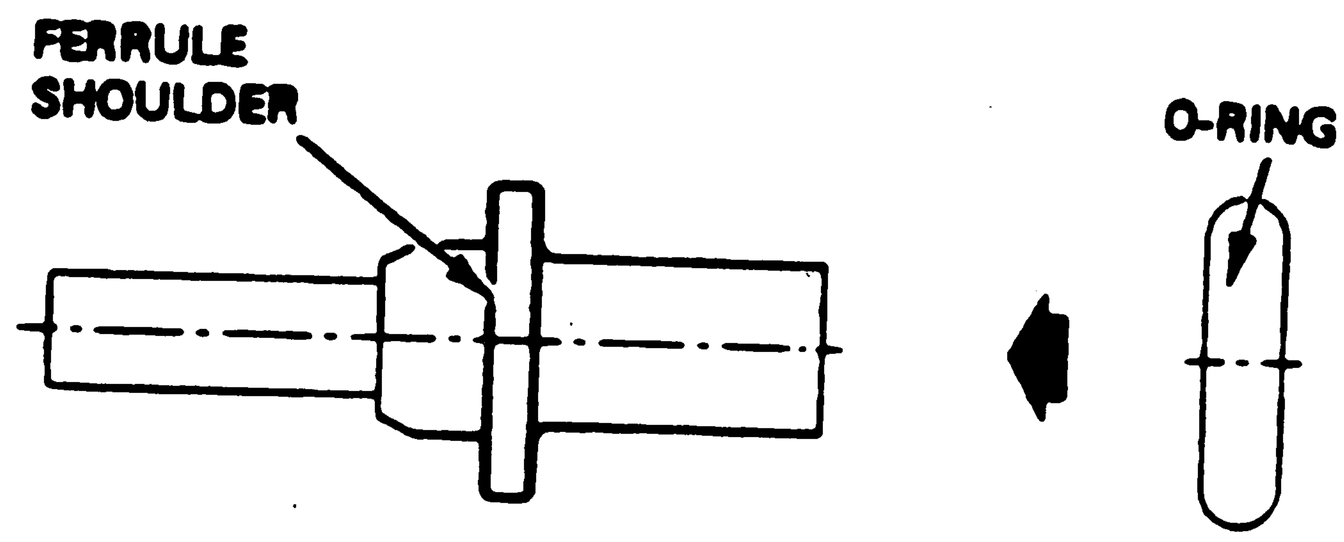


Fig. 11

14. Inject epoxy into the ferrule using Epoxy Applicator 501473-2 until it appears at the tip. Continue to inject a small amount of epoxy while withdrawing the applicator. See Figure 12.

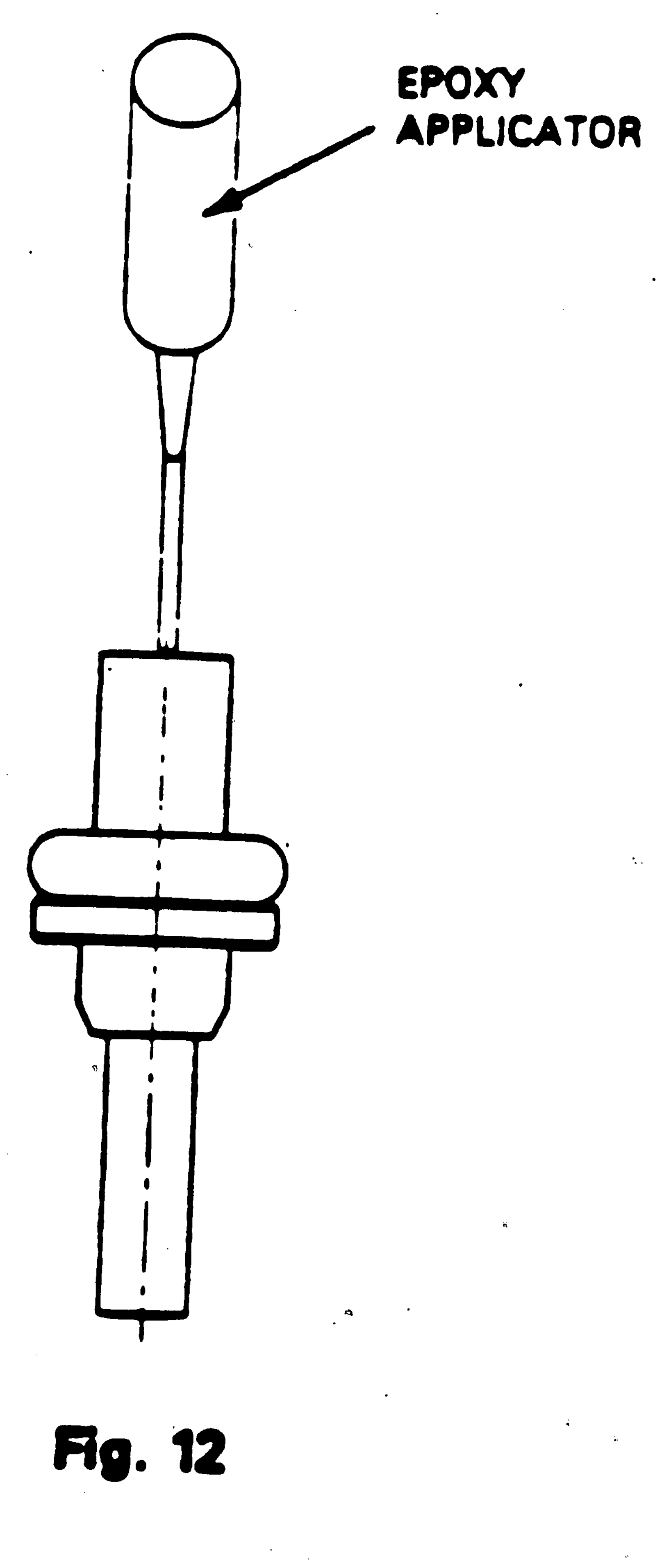


Fig. 12

15. Install a ferrule over one of the fibers. Carefully position the ferrule in its nest in the fixture. Push the buffered fiber into the track in the fixture. Repeat for the second fiber. See Figure 13.

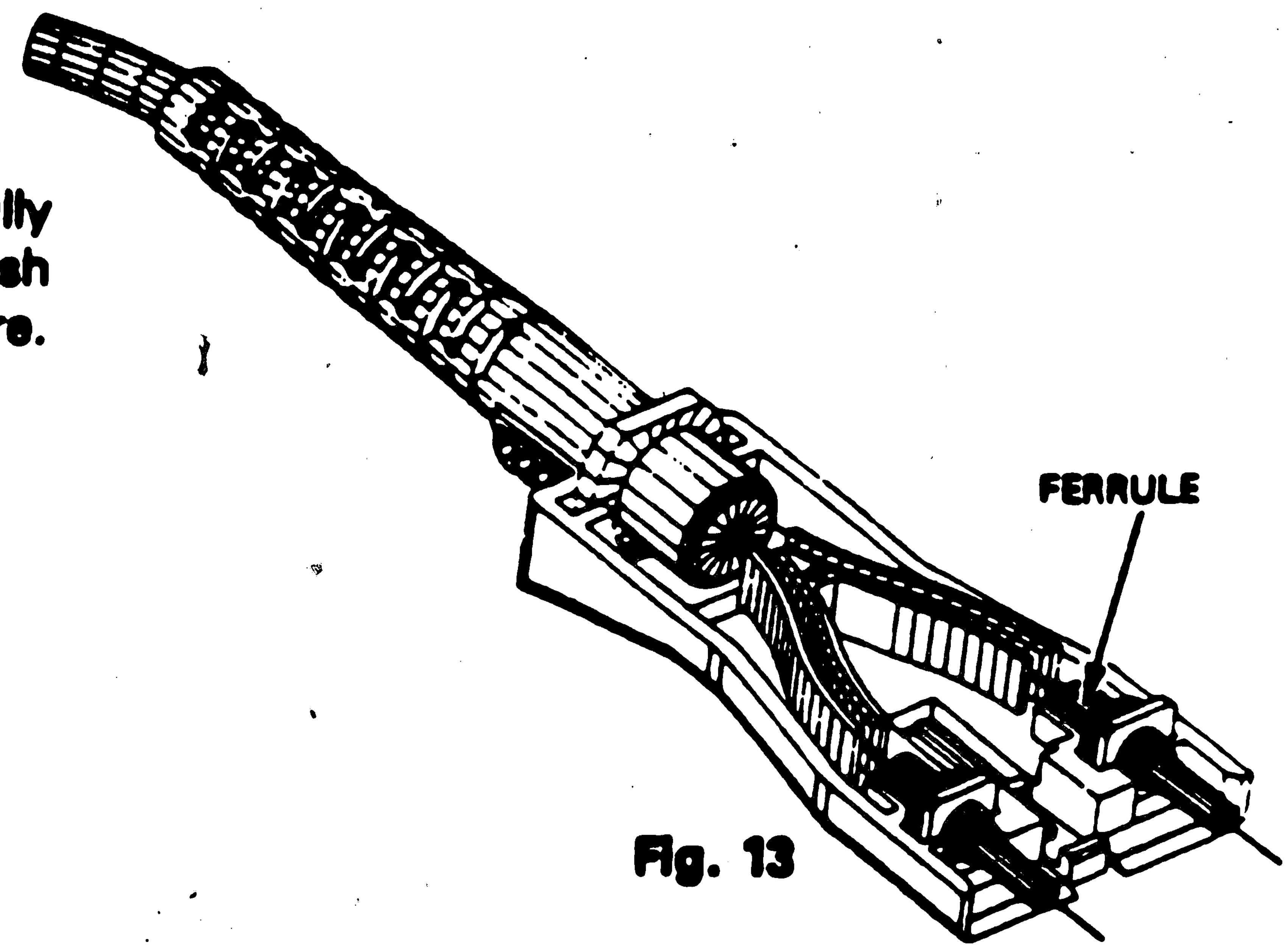


Fig. 13

16. Place the top fixture body on the lower body, and screw the nut onto the fixture to secure both halves (see Figure 14). Place the protective sleeve on the assembly.

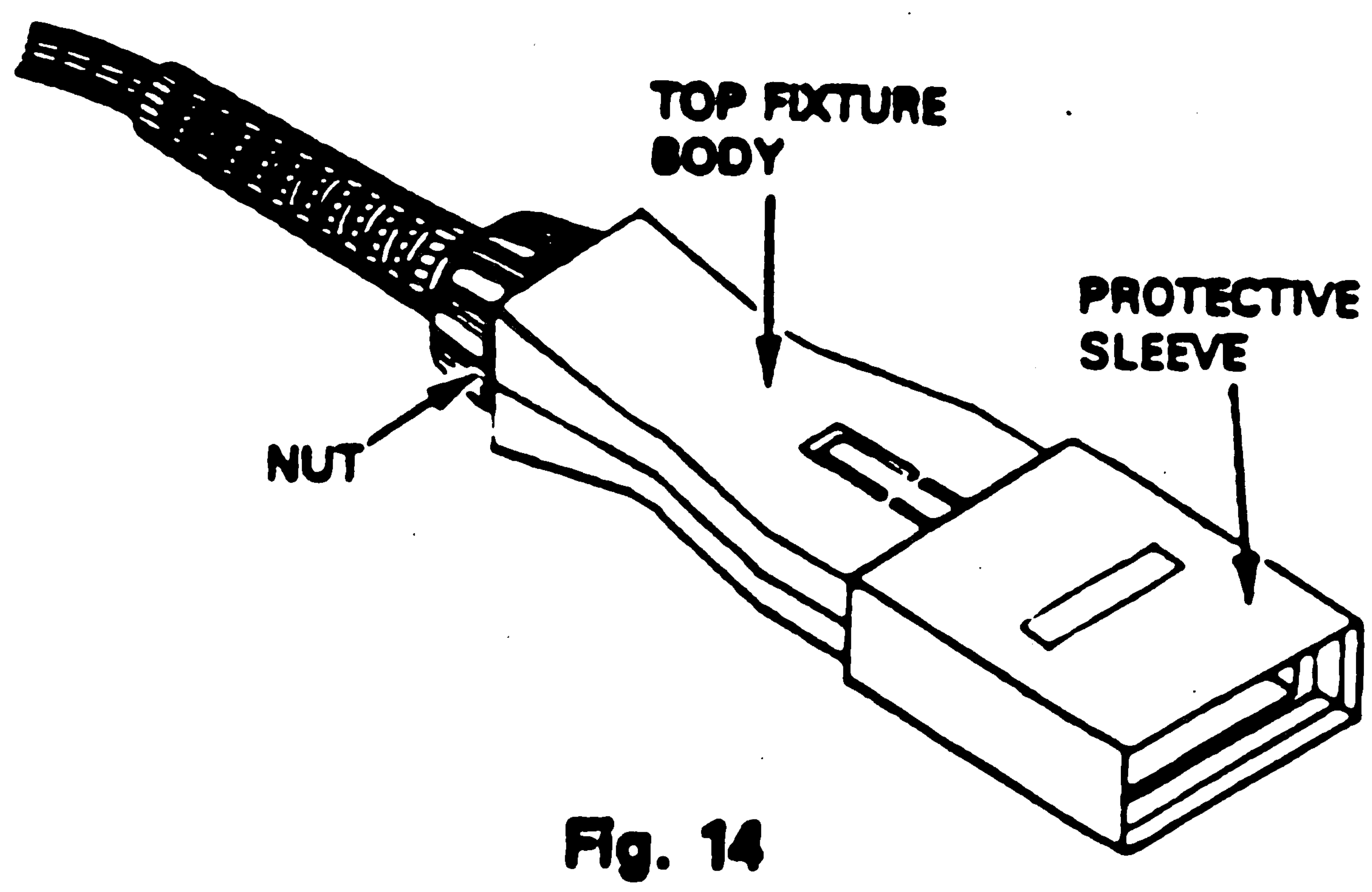


Fig. 14

17. Hang the assembly, ferrules down, and cure at:

Epoxy 501195-1 — 4 hr. at 65° C
24 hr. at 25° C

18. Remove the protective sleeve. With the cable assembly still in the assembly fixture, lightly scribe each fiber with Scribe Tool 228793-1; then pull the fiber straight away from the front of the ferrule. See Figure 15.

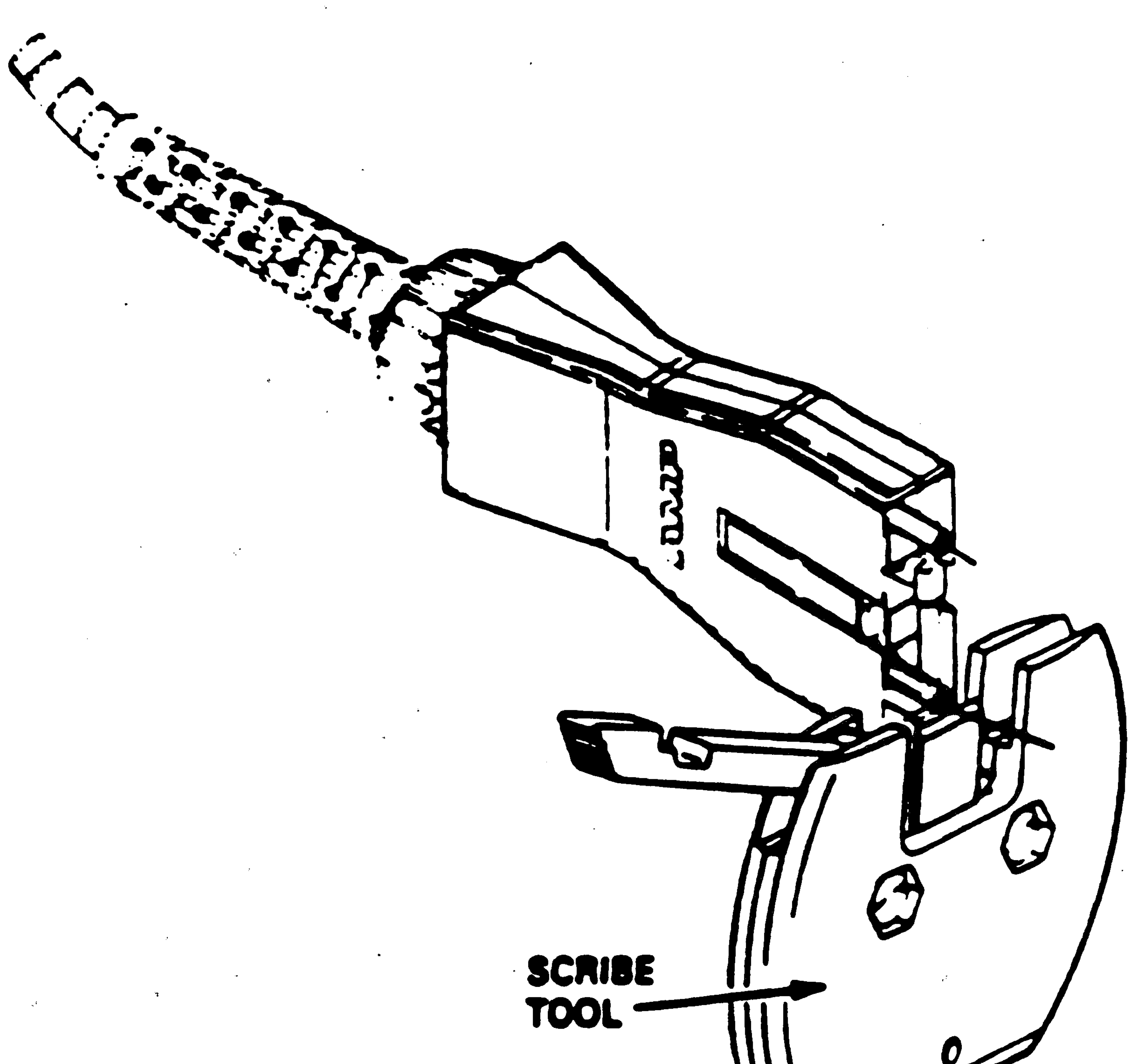


Fig. 15

19. Put the polishing bushing (part of the assembly fixture) on the assembly fixture. See Figure 16.

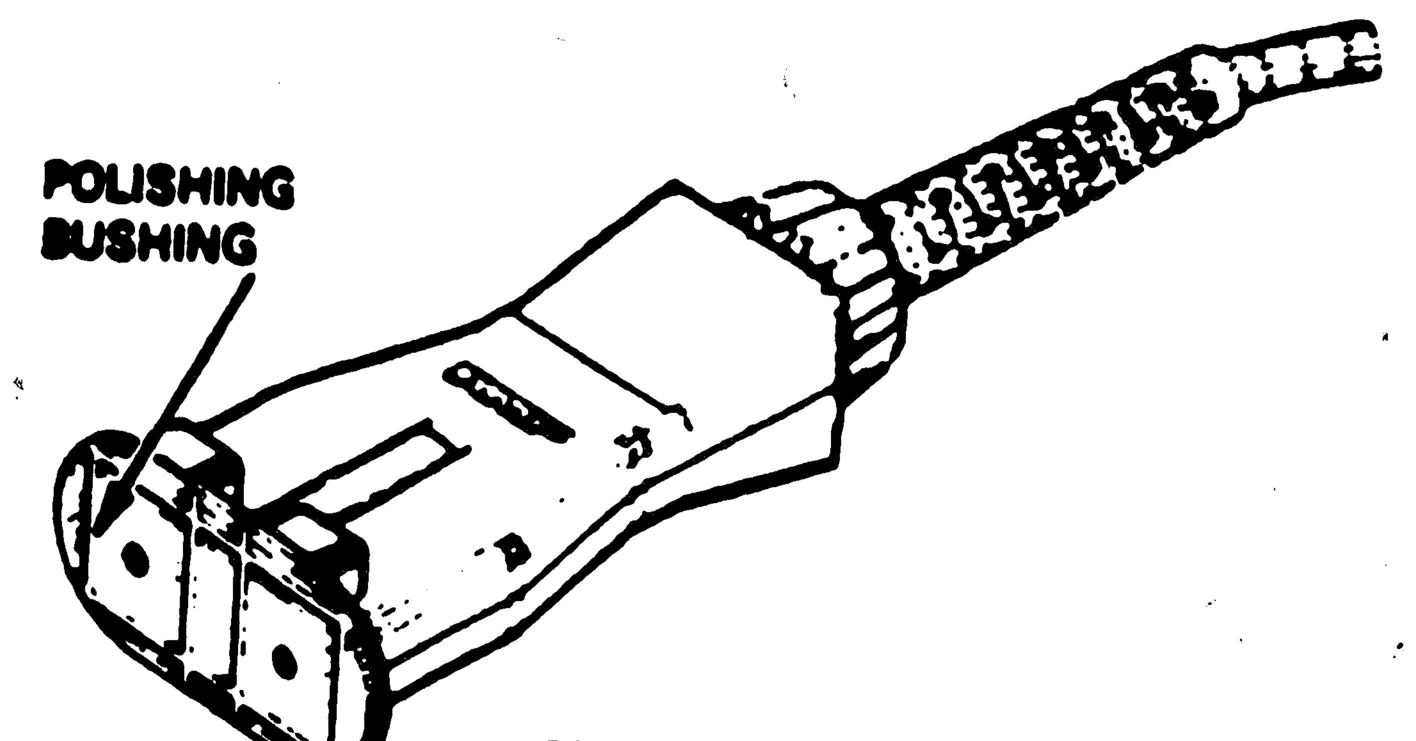


Fig. 16

20. Place the resilient pad on the polishing surface; place a piece of 5-μm film on the pad. Dry-polish the connector on the film using a figure-8 pattern until the tip of the ferrule turns light blue (vary the pressure and/or rotate the fixture as necessary). See Figure 17.

21. Replace the 5-μm film with 1-μm film and polish the connector until all of the epoxy is gone.

22. Replace the 1-μm film with .3-μm film and finish polishing.

WARNING *Never look into an optical fiber when optical power is "on." Many of the light sources used, although invisible, can injure the eyes and cause blindness.*

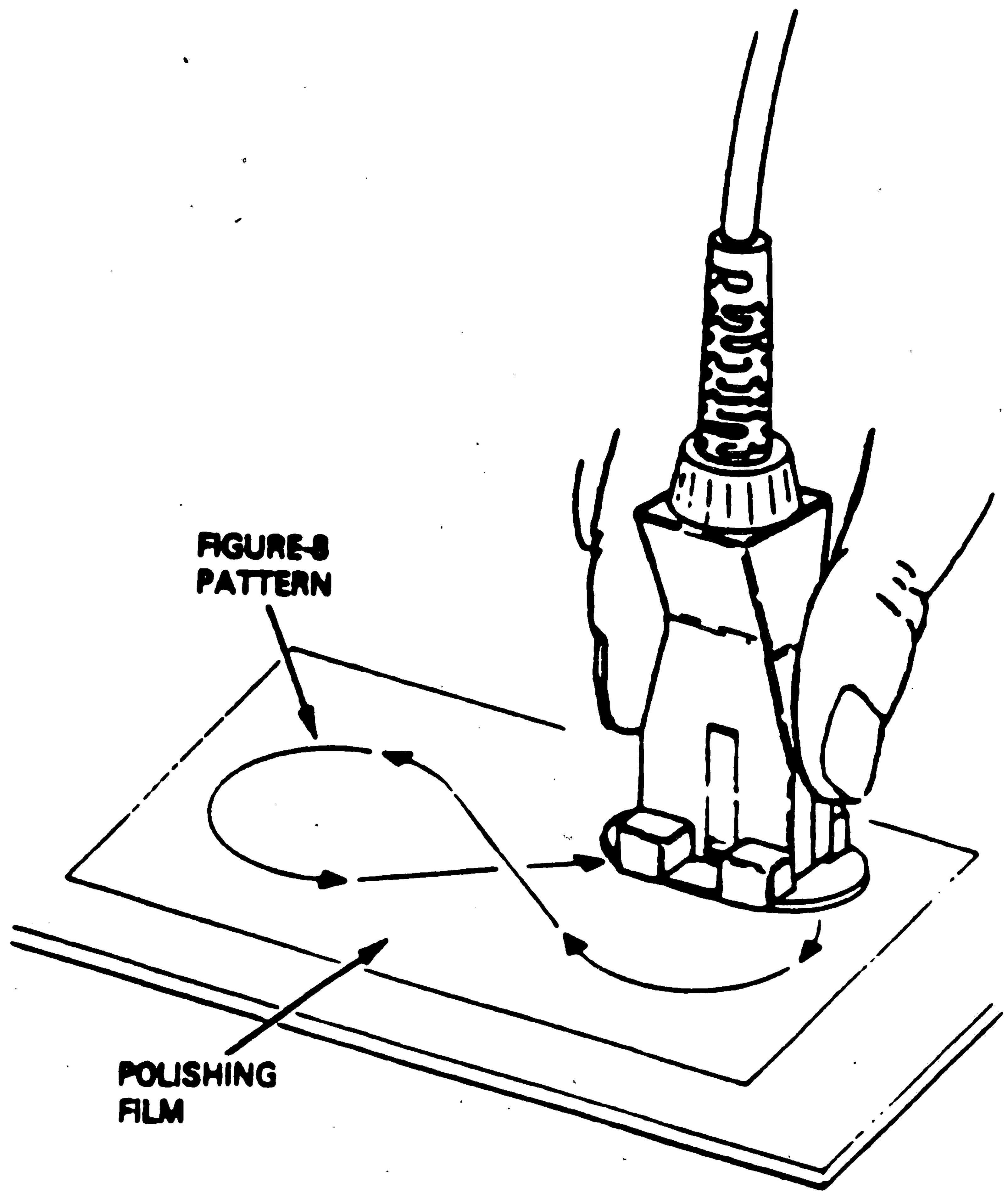


Fig. 17

23. Check the polishing with a microscope or a magnifier. Check for the following (see Figure 18):

— Small chips in the outer ring are permissible. Large chips, or chips in the center of the fiber, mean that more polishing is needed, or that the termination is unacceptable, and the fiber must be reterminated.

— Deep scratches on the ferrule indicate that the ferrule should be polished more on the .3-μm film.

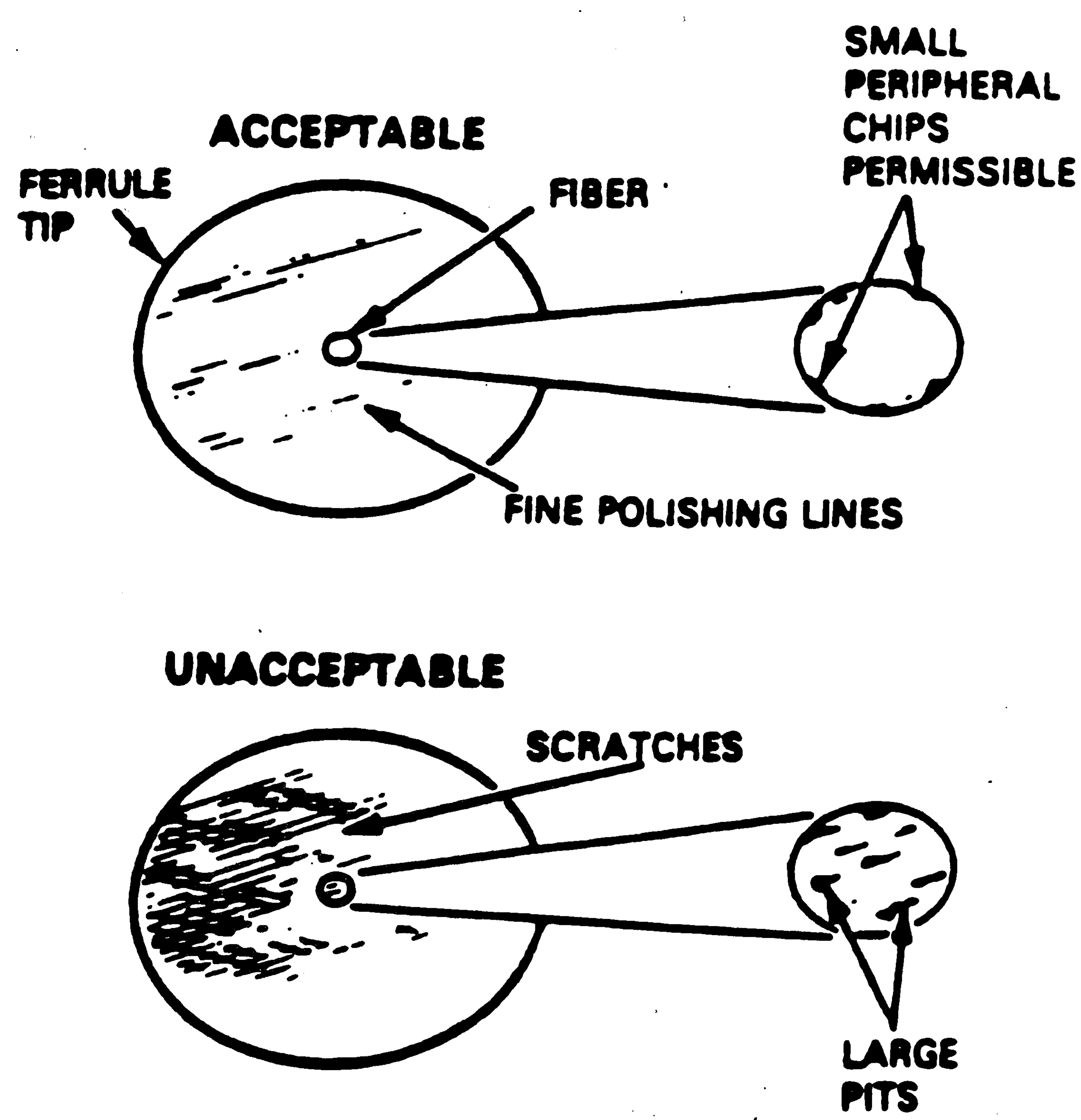


Fig. 18

24. Remove the polishing bushing and the assembly fixture.

25. Place the two polished ferrules in the bottom half of the housing, snap on the top half (the half with keying slot), and screw the nut onto the housing. See Figure 19.

NOTE *Be sure to identify (with a label or other means) the input and output fibers.*

26. Install keys as required for your application. Two keys are included with the connector — a Type M key and a Type A-B key.

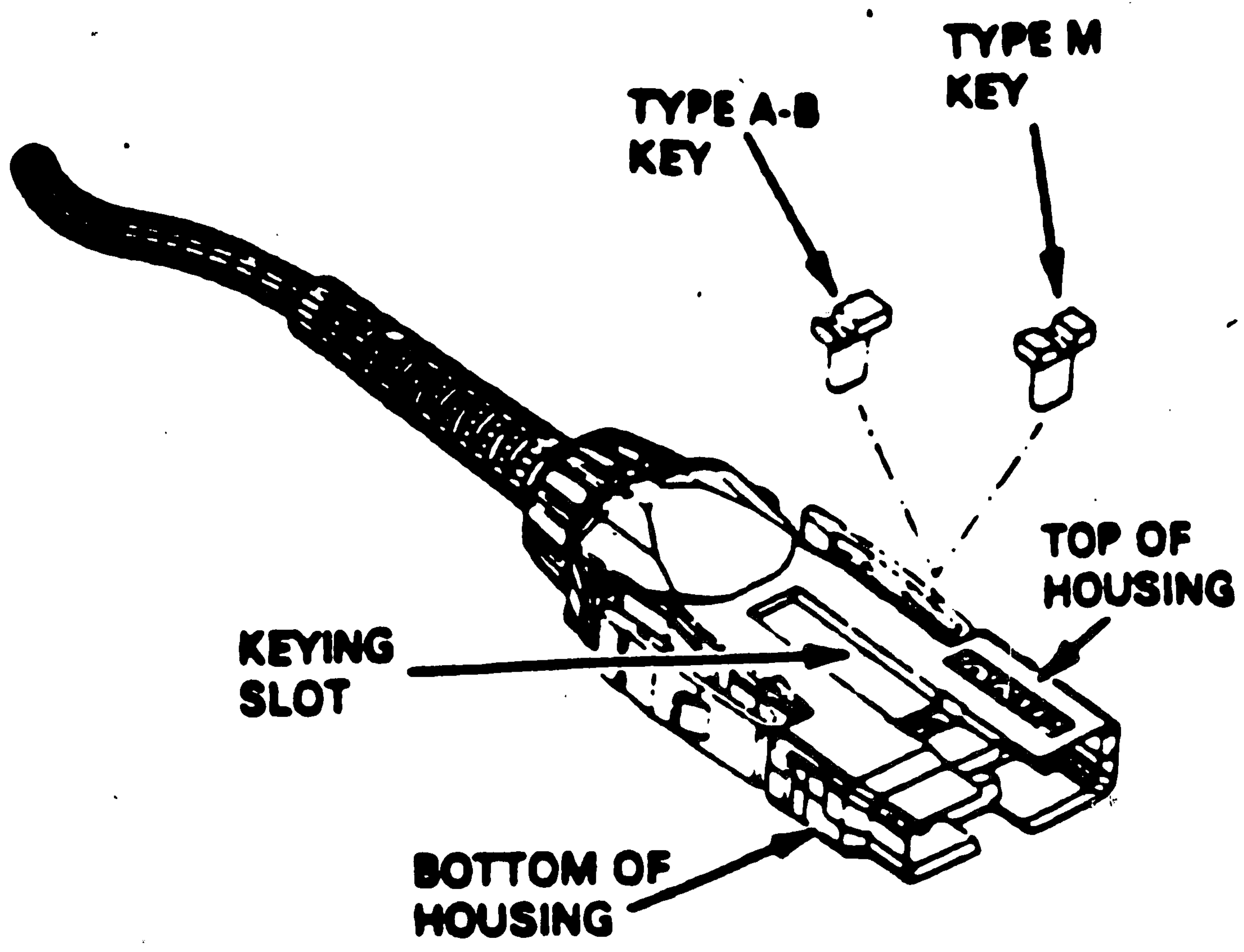


Fig. 19

E.2 Special Termination Procedures

The following sections include additional information on **FSD** connector installation procedures:

Female Outlets:

- Caution should be exercised when installing outlet covers. The outlet box should provide ample room for the excess optical fiber. The outlet cover should be flush with the wall and wall outlet.
- The FSD outlets should be put together carefully, making sure that all pieces are snapped together tightly (See section B on page 143).

Male Jumper Cords:

- Jumper cords should be long enough to avoid any stress.
- Breakout sections on jumper cables should anchored securely to kevlar strength member on the main cable.
- Ferrules should applied only to cable pairs that have been stripped to the same length. Equal length is of importance when making FSD jumper cable assemblies (See page 146 in section E.1.2).

The following sections include additional information on **ST** connection installation procedures:

- Connector ends should be fastened securely to the stripped kevlar. This is done in the crimping stage (See page 136 in section E.1.1).
- Cautioned should be exercised when polishing the ST ceramic barrels. Finer grades of polishing film should be used before all the epoxy is ground from the ferrule surface. This will alleviate most scratches.
- Use a polishing pad between the polishing film and glass plate surface. The will protect the ferrule surface from being polished too abruptly (See page 139 in section E.1.1).

F. Vita

The author is a 24 year old *Network Planning Engineer* working for Bell Communications Research in Red Bank, NJ. His interests include optical fiber data transmission and LAN architecture development. He received his B.S. in Electrical and Computer Engineering from Clarkson University in 1986 and his M.S. in Electrical Engineering from Lehigh University in 1988.

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